J. Simpson Walker

RUDIMENTARY AND PRACTICAL INSTRUCTIONS

ON

THE SCIENCE

OF

RAILWAY CONSTRUCTION

FOR THE USE OF

Beginners and those who have commenced Practice.

IN TEN DIVISIONS:

- MENSURATION OF SUPERFICIES OR SURFACES, AND SOLIDS.
- LAND SURVEYING.
- ENGINEERING SURVEYING AND TAKING THE LEVELS.
- ON LAYING OUT A RAILWAY, CURVES.
- SETTING OUT THE SURFACE, WIDTHS OF THE CUTTINGS AND EMBANKMENTS.
- VI. RAILWAY TUNNELLING.
- VII. MECHANICAL DETAILS AND ILLUSTRATIONS.
- VIII. STATIONS.
- IX. FORMS OF RETURNS AND SPECIFICATIONS.
- X. PERMANENT WAY, EARTH-WORK, DRAINAGE AND BALLAST, SLEEPERS, RAILS ETC.

Stephenson, Sir Rowland Macdonald

WITH UPWARDS OF 150 ILLUSTRATIONS.

LONDON:
VIRTUE BROTHERS & CO., 26, IVY LANE,
PATERNOSTER ROW.
1866

ADVERTISEMENT TO THE SECOND EDITION.

THE First Edition of the Rudimentary Volume on Railway Details, being Vol. LXII. in the Series, written in 1850 by Sir Macdonald Stephenson, and gratuitously presented by him in aid of these publications of technical works, specially written in a simple, elementary and practical form, has been for some time out of print. A new one or second edition is presented with additions, adding to its elementary and practical character; and with the kind sanction of Sir Macdonald Stephenson, Divisions seven, eight, and nine, those parts originally written by him, are again given as models or examples for the student. Divisions one to six are purely of an elementary kind, as short and easy instructions for young men beginning their career, who are desirous by a shorter road of accomplishing those elementary examples, essential for them to learn. Division ten is entirely practical. The Permanent Railway Company gave me permission to copy from their Reports and Papers, but as Mr

Holley, of New York, in his published Volume of the present year has done the same, more fully and illustratively than would be done by another, I am indebted to that gentleman for the copious extract made, as will be seen in Division ten. To all practical men the work of Mr. Holley, published in a 4to volume, is recommended (not in deprecation of Mr. Dempsey's practical work, but as an auxiliary to the same) as a very excellent work for use in the construction and the working of railways.

J. W.

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SCIENCE OF RAILWAY CONSTRUCTION.

RAILWAYS.

INTRODUCTION.

Railways may, with equal force and propriety, be defined as the great modern instrument of civilisation—the detached links of that extended chain which, at no distant date, shall connect the remotest ends of the world, and exercise upon the whole family of man a humanising and irresistible influence.

Their general principles may be regarded as the adaptation of mechanical contrivance for the diminution of friction in the ordinary appliances of locomotion, and a consequent reduction of time and space proportioned to the degree of perfection attained in the means employed.

Of their origin, progress, and present position, it is admitted that the collieries first benefited by the use of wood and cast-iron tramways, to convey heavy loads for short distances, at a cost for traction which speedily attested its superiority over the common road. The soundness of the principle gradually induced its extension. Flat stone tramways and wrought-iron rails in endless variety of form underwent the test of examination and experiment, and after several years, and great, though perhaps unavoidable cost, the Railway system is firmly established upon a secure and solid base, with clear and defined general principles, and in course of rapid and universal extension.

In considering the comparative advantages of the ı spective plans of construction and working, it must remembered that the entire burthen of the costly expe ment has been borne by England, and that foreign stat have prudently awaited the results, and lost no time profiting by them. The general characteristics of t English works are solidity and strength, durability a grandeur; of the Belgian, Prussian, and others of t continental works, simplicity, judicious economy, a especial adaptation of the principle to the exigencies a resources of the respective countries; and of the Americ works, rigid and parsimonious economy, having for object the extension over the greatest possible distance the least quantity of materials, with a view to the speedi though least efficient opening of the communication, a assuming the cost of future relaying to be less onerous th the loss of interest upon the heavier and more substan works.

Among the objections founded on past experience particular practices, may be enumerated the extremes of English and American works. A judicious combin of the solidity of the former with the simplicity c latter, avoiding the manifest defects of both, will prc afford the means of securing the greatest attainable a of permanent benefit, at the least possible cost.

That the construction, maintenance, and working be so regulated with reference to the cost and the v the community, as to admit of establishing the possible rate of fares; the neglect to recognise portance of not entailing heavy after-expenses, overrated impression of the advantage of cheap coı *at the outset,* and a too ready adoption of the *views of enthusiastic* admirers of the principle,

adapt to circumstances totally dissimilar a mode of construction and description of work which, however suitable in the one case, is frequently the least applicable in the other:—The practical illustration of these views will be contained in this portion of this little work, in which will be found a collection of all the best Railway operations, arranged in such form as to admit of comparison with others.

The most interesting inquiry in connection with the subject of Railways, now that their use in England has become so widely diffused, is the probability and the most effectual means of their extension still further in the British colonies, under circumstances and within a period to render it probable that the benefit shall not be limited exclusively to the particular colony, but shall be largely participated in by the country from which the useful impulse shall have been imparted.

To this end, certain well understood precautions are indispensable. The extremes of extravagance and parsimony will be found alike injurious. The difficulty of maintaining a middle course is at all times much increased by the injudicious zeal and misplaced earnestness of the several advocates of their respective plans. An English railway engineer, unacquainted with the construction of similar works in America, will too frequently disregard the really economical features of the foreign work; while an American, imbued with the undeniable benefits which have attended the cheap, light, and rough works of his own country, will scarcely give the consideration, or attach the weight which is undoubtedly due to the stability and permanent character of the English system of construction.

Under the recently adopted practice of appropriatin *surplus* profits to reconstruction, the Boston, Lowell,

other railway companies, have completed a second line of rails of a more permanent description, and without interruption to the traffic. As a single line, it realised 12½ per cent. to the stockholders, of which 8 per cent. was divided, and 4½ per cent. set aside to accumulate for this purpose.

The ingenuity of the engineering world at large has been unceasingly directed for several years to the solution of that problem, which should constitute the groundwork of our colonial railway practice, viz., the attainment, in the construction, of a stability which shall be at the same time the most economical and the most permanent; neither building too strong, at a prejudicial cost of interest for plant, nor refining too closely to the increase of current repairs and cost of maintenance.

It is not unreasonable to assume that in each country the results of this steady direction of especial talent upon one common object should have produced its fruits; and it is no less certain, that in our colonies and in India there exist many points of strict analogy with the practice both of Europe and America; the observance or disregard of which, with the judgment exercised in their suitable adaptation to the particular exigencies of the case, will constitute at the same time one of the most difficult and important duties of those who are engaged in these works.

Past experience is to be regarded as a warning beacon. No justification can be admitted for future errors. No plea will be recognised for experimentalising. Sufficient precedents exist for all possible emergencies in the collective operations of the various states of Europe and America.

It is to be regretted that among the numerous and able *publications* which have issued from the press, at home *

* "*Practical Railway* Engineer," by G. D. Dempsey, 4to. 1855.

and abroad, there should be no one devoted to the particular purposes of comparative railway engineering, from which the several objects to be accomplished being shown, the means adopted under the varying circumstances should be given, by which the comparative sufficiency or defects, the excessive or inadequate strengths and proportions of the means to the end, and the relative expenses of the several systems, should be so accurately ascertained as to afford sure and unerring data for future guidance.

Such a desideratum it is intended, in the following part of this little work, to initiate upon the limited and unpretending scale which of necessity characterises an elementary and popular production, in the hope and expectation that it may induce those who are so well able to accomplish the object fully and effectually, to consider the subject not undeserving their attention, and that a portion of that time which, among railway engineers especially, has for so long been exclusively devoted to the designing and construction of those splendid monuments of science, talent, perseverance, and public spirit, may be occasionally applied to the elucidation of principles, the illustration of practice, and the comparative merits and demerits, advantages or disadvantages over similar works, with a view to the establishment of fixed, well founded, and clearly demonstrated principles.

With these few remarks, we may proceed at once to the consideration of the study, in acquiring perfectly the simple sciences of Mensuration of Superficies or Surfaces, of Solids, Engineering, Surveying, and Levelling; on Laying out Railway Curves, Cuttings, Embankments and Tunnels. These fundamental principles are essential in the formation of a railway engineer.

To obtain parliamentary sanction to an English railwa

certain stipulations are required to be scrupulously observed:—the direction and precise length of the line to be shown:—the points of junction with others:—the properties passed through and affected:—and a uniform scale to be adhered to. The limits of deviation on the plans are 100 yards on each side of the line, and 5 feet in the sections except in passing towns, where two feet only are allowed, and the radius of curvatures is limited to 1 mile.

Due provision will be made by the engineer for the quality of materials, workmanship, proportions, and form of laying, and on all points upon which it is indispensable that the contractors should be bound in their contracts.

We will now commence with our elementary studies, essentially to be mastered by the student, as in parts 1 to 6, as follows, beginning with Mensuration, &c.

DIVISION I.

MENSURATION OF SUPERFICIES OR SURFACES.

THE area of a surface is estimated by the number of squares in that surface, without regard to thickness, the side of those squares being 1 inch, 1 foot, 1 yard, &c. Hence the area is said to be so many square inches, or square feet, or square yards, &c.

A Table of Square Measure.

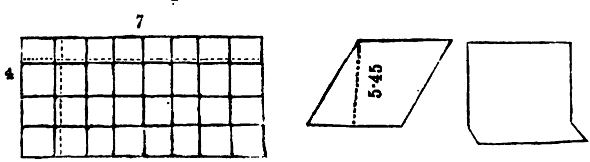
Sq. ins.	Sq. feet.	Sq. yards.	Sq. poles.	Sq. rods.	Acres.	Square mile.
144	1					
1,296	9	1				
39,204	272¼	30¼	1			
	1,089	1,210	40	1		
	43,560	4,840	160	4	1	
		3,097,600	102,400	2,560	640	1

PROBLEM I.

To find the area of a parallelogram, whether it be a square, a rectangle, a rhombus, or a rhomboid.

RULE.—Multiply the length by the breadth or perpendicular height, and the product will be the area. (See first figure.)

1. The length of a rectangular board is 7 feet and its breadth 4 feet: required its area in square feet.



By the Rule $7 \times 4 = 28$ square feet, the area required.

2. The side of a square is 18 inches; required its area in square feet. (See last figure.)

$$\frac{18 \times 18}{12 \times 12} = \frac{27}{12} = 2\tfrac{1}{4} \text{ square feet, the area required.}$$

3. To find the area of a rhombus, the length of which is 6·2 feet, and its perpendicular breadth 5·45. (See second figure.)

$$6{\cdot}2 \times 5{\cdot}45 = 33{\cdot}79 = 33\tfrac{4}{5} \text{ square feet nearly.}$$

4. The length of a table is 7 feet 8 inches, and its breadth 3 feet 10 inches; required its area.

ft.	in.	
7	8	
3	10	
23	0	
6	4	8
29	4	8

Here the operation is performed by duodecimals, and the area is found to be 29 square feet, 4 inches (or 12ths), 8 parts (or $\frac{8}{144}$ths).

Problem II.

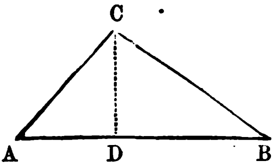
To find the area of a triangle.

Rule I.—Multiply the base by the perpendicular height, and take half the product for the area.

Rule II.—When the three sides only are given: add the three sides all together, and take half the sum; from the half sum subtract each side separately; multiply the half sum and the three remainders continually together; and take the square root of the last product for the area of *the triangle.*

1. Let the base A B equal 42 feet, and the perpen- *dicular C D equal 33* feet; required the area in square yards.

By Rule I.
$42 \times 33 \div 2 = 693$ square feet, and $693 \div 9 = 77$ sq. yards.



2. To find the number of square yards in a triangle, the sides of which are 13, 14, and 15 feet.

By Rule II.

```
           13                  21
           14                   6
           15                 ———
           ——                 126
         2)42                   7
           ——                 ———
  ½ sum    21   21   21       882
           13   14   15         8  9
           ——   ——   ——      ——————
remainders  8    7    6       7056(84 square feet,
                              64    = 9⅓ sq. yds. Ans.
                              ———
                           164)656
                               656
```

3. The base of a triangle is 18 feet 4 inches, and its height 11 feet 10 inches; required its area.

```
   ft.  in.
   18    4
   11   10
  ——————————
  201    8
   15    3   4
  ——————————————
2)216   11   4
  ——————————————
  108ft. 5'  8" area required.
```

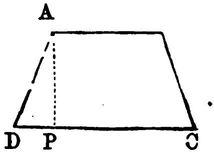
Problem III.

To find the area of a trapezoid.

Rule.—Add together the two parallel sides, multiply t

sum by the perpendicular distance between them, and take half the product for the area.

1. In a trapezoid the parallel lines are A B 7·5, and D C 12·25, also the perpendicular distance A P is 15·4 feet; required the area.



$$\begin{array}{r} 12{\cdot}25 \\ 7{\cdot}5 \\ \hline 19{\cdot}75 \\ 15{\cdot}4 \\ \hline 7900 \\ 9875 \\ 1975 \\ \hline 2)304{\cdot}150 \\ \hline 152{\cdot}075 \end{array}$$

152·075 *square feet. Ans.*

2. Required the area of a trapezoid, the parallel sides being 21 feet 3 inches and 18 feet 6 inches, and the distance between them 8 feet 5 inches.

Ans. 167 *sq. ft.*, 3′ 4″ 6‴.

Problem IV.

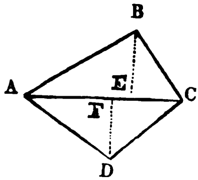
To find the area of a trapezium.

Rule.—Divide it into two triangles by a diagonal, then find the areas of these triangles, and add them together.

Or, if the two perpendiculars be let fall on the diagonal, from the two other opposite angles, the sum of these perpendiculars being multiplied by the diagonal, half the product will be the area of the trapezium.

1. Find the area of the trapezium A B C D, the *diagonal A C being* 42, the perpendicular B E 18, and the *perpendicular D F 16.*

18
16
—
34 Sum
42
—
68
136
———
2)1428
———
714 *Ans.*



2. How many square yards of paving are in the trapezium, the diagonal of which is 65 feet, and the two perpendiculars let fall on it are 28 and 38·5 feet?

Ans. 240·1388 *yards.*

PROBLEM V.

To find the area of a regular polygon.

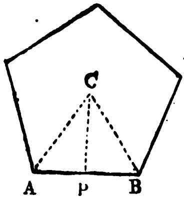
RULE I. Multiply the sum of the sides or perimeter of the polygon by half the perpendicular from its centre to one of its sides, and the product will be the area.

RULE II.—Multiply the square of the side of the polygon by the number opposite its name, in the column headed "Areas," in the following table, and the product will be the area required.

TABLE OF POLYGONS.

No. of Sides.	Name.	Rad. Inscribed Circle.	Rad. Circumsc. Circle.	Areas.
3	Trigon or equilateral-triangle .	·2887	·5773	·4330
4	Tetragon or square . . .	·5000	·7071	1·0000
5	Pentagon	·6882	·8506	1·7205
6	Hexagon	·8660	1·0000	2·5981
7	Heptagon	1·0383	1·1524	3·6339
8	Octagon	1·2071	1·3066	4·8284
9	Nonagon	1·3737	1·4619	6·1818
10	Decagon	1·5388	1·6180	7·6942
11	Undecagon	1·7028	1·7747	9·3656
12	Dodecagon	1·8660	1·9319	11·196

FORMULÆ.



Let s = A B = side of the polygon, p = C P perpendicular from the centre on A B, n = number of sides of the polygon, and a = its tabular area; then the area $A = \frac{1}{2}\, n\, p\, s$, and $A = a\, s^2$. Also

$$s = \sqrt{\frac{A}{a}} = \frac{2\,A}{n\,p}, \text{ and } p = \frac{2\,A}{n\,s}.$$

Note.—The formulæ may be omitted, being only required in particular cases.

1. Required the area of a regular pentagon, the side A B of which is 25 feet, and the perpendicular C P = 17·205.

By Rule I.

```
              17·205
25 × 5 = 125 = perim.
         ------
          86025
         34410
        17205
         ------
     2)2150·625
      ---------
     1075·3125 sq. feet.
```

By Rule II.

```
 1·7205 table area.
   625 = 25²
 --------
   86025
  34410
 103230
 --------
 1075·3125 sq. feet. Ans.
```

2. Required the area of a hexagon, the side of which is 20 feet. *Ans.* 1039·23 *square feet.*

3. Required the side of a decagon, the area of which is 16 square feet.

By the third formula, the side $s = \sqrt{\frac{A}{a}}$, that is,

$$\sqrt{\frac{16}{7{\cdot}6942}} = 1{\cdot}442 \text{ feet} = 1 \textit{ foot } 5{\cdot}3 \textit{ inches.}$$

PROBLEM VI.

To find the area of a circle when the radius or half diameter is given.

RULE I—Multiply the square of the radius by 3·1416 for the area.

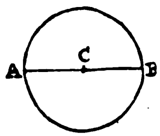
To find the area of the circle when the circumference is given.

RULE II.—Multiply the square of the circumference by ·07958.

1. Required the area of a circle the radius of which is 5 feet.

By Rule I.

$$\begin{array}{r} 3{\cdot}1416 \\ 25 = 5^2 \\ \hline 157080 \\ 62832 \\ \hline 78{\cdot}5400 \end{array}$$ *sq. feet.*



2. The circumference of a circle is 18·4 feet, what is its area? *Ans.* 26·92 *square feet.*

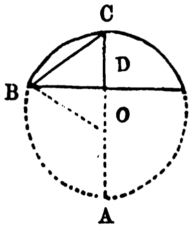
3. How many square yards are in a circle whose diameter is 3½ feet? *Ans.* 1·069 *square yards.*

PROBLEM VII.

The chord (B E) *and the height or versed sine* (C D) *of an arc* (B C E) *of a circle being given, to find the diameter* (A C) *and the chord of half the arc* (B C).

RULE.—Divide the square of half the chord B E by the height C D; to the quotient add C D, and the sum will be the diameter A C; half of which is the radius B O or C O. And to find B C, multiply A C by C D, and the square root of the product is the length of B C.

1. The chord of an arc is 48 feet, and its height 18; required the diameter of the circle of which the arc is a part.



By the Rule $24 = \frac{1}{2}\,BE = BD$

$$\begin{array}{r} 24 \\ 24 \\ \hline CD = 18)576 \\ \hline 32 \\ 18 = CD \\ \hline 50 \text{ feet} = AC. \end{array}$$

Whence the radius B O = 25 feet.

Problem VIII.

To find the diameter and circumference of a circle, the one from the other.

Rule I.—As 7 is to 22, so is the diameter to the circumference; as 22 is to 7, so is the circumference to the diameter.

Rule II.—As 1 is to 3·1416, so is the diameter to the circumference; as 3·1416 is to 1, so is the circumference to the diameter.

1. Find the circumference of a circle whose diameter is 10.

By Rule I. $7 : 22 :: 10 : 31\frac{3}{7}$

$$\begin{array}{r} 10 \\ \hline 7)220 \\ \hline 31\frac{3}{7} = 31{\cdot}42857, \textit{ Ans.} \end{array}$$

By Rule II. $1 : 3{\cdot}1416 :: 10 : 31{\cdot}416$

$$\begin{array}{r} 10 \\ \hline 31{\cdot}4160 \end{array}$$ which is nearer the truth.

2. *If the diameter* of the earth be 7958 miles, as it is

very nearly, what is the circumference, supposing it to be exactly round?

$$3{\cdot}1416 \times 7958 = 25000{\cdot}8528 \text{ miles.}$$

3. Required the diameter of a coach wheel that turns round 500 times in travelling a mile.

$$5280 \div 500 = 3\,ft.\ 5{\cdot}05\ in.$$

PROBLEM IX.

To find the length of any arc of a circle.

CASE I.—When the degrees in the arc and the radius are given.

RULE I.—As 180° is to the number of degrees in the arc, so is 3·1416 times the radius to its length.

CASE II.—When the chord of half and of the whole arc are given.

RULE II.—From 8 times the chord of half the arc subtract the chord of the whole arc, and take $\frac{1}{3}$ of the remainder for the length of the arc nearly.

1. To find the length of an arc of 30 degrees, the radius being 9 feet.

By Rule I.

$$\begin{array}{r} 3{\cdot}1416 \\ 9 \\ \hline \end{array}$$

$$180 : 30 :: 28{\cdot}2744 : 4{\cdot}7124 \text{ feet.}$$

2. The chord BE of the whole arc being 4·65374 feet, and the chord BC of the half arc 2·34947; required the length of the arc. (See fig. to Problem VII.)

By Rule II.

$$\begin{array}{r} 2{\cdot}34947 \\ 8 \\ \hline 18{\cdot}79576 \\ 4{\cdot}65874 \\ \hline 3)14{\cdot}13702 \\ \hline \end{array}$$

Ans. 4·71234 feet.

3. Required the length of a circular iron girder, the span (B E) of which is 48 feet, and the rise (C D) at the crown 18 feet. (See fig. to Problem VII.) *Ans.* 64 *feet.*

Problem X.

To find the area of a sector of a circle.

Rule I.—Multiply the radius by half the arc of the sector for the area.

Note.—The arc may be found by Prob. IX.

Rule II.—As 360 is to the degrees in the arc of the sector, so is the whole area of the circle to the area of the sector.

1. What is the area of the sector C A D B, the radius A C=C B being 10, and the chord A B=16?

By Rule II., Prob. IX.

$100 = AC^2$
$64 = AE^2$

$36 (6 = CE$
$10 = CD$

$4 = DE$

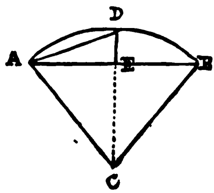
$16 = DE^2$
$64 = AE^2$

$80 (8·9442719 = AD$
8

$71·5541752$
16

---

3) 55·5541752
2) 18·5180584 arc A D B



By Rule I., Prob. X. . . . . . 9·2590297 = half arc
10 = radius

92·590297 *Ans.*

2. Required the area of a sector, the arc of which contains 96 degrees, the diameter being 3 feet.

$$\begin{array}{r} \cdot 7854 \\ 9 = 3^2 \\ \hline 7 \cdot 0686 = \text{area of the whole circle.} \end{array}$$

Then by Rule II.,

as $360^\circ : 96^\circ :: 7 \cdot 0686$

or, as $30^\circ : 8^\circ :: 7 \cdot 0686 : 1 \cdot 88496$ *sq. feet. Ans.*

3. What is the area of a sector, the radius of which is 10 feet, and the arc 20 ? *Ans.* $11\frac{1}{9}$ *square yards.*

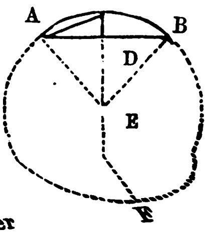
Problem XI.

To find the area of a segment of a circle.

Rule I.—Find the area of a sector having the same arc as the segment, by the last problem; find also the area of the triangle formed by the chord of the segment and the two radii of the sector: then take the difference of these two areas, when the arc is less than a semicircle, for the required area; but add for the area when the arc is greater than a semicircle.

Rule II.—Divide the height, or versed sine of the segment, by the diameter, and find the quotient in the column of versed sines, in the Table for that purpose; take out the corresponding area in the next column on the right hand, and multiply by the square of the diameter for the area.

1. Required the area of the segment A C B D A, its chord A B being 12, and the radius A E or C E 10 feet.



Put r = A E, C = A B, v = C D, p = E D, t = tabular area, and a = arc A C B, then

$$A = \tfrac{1}{2}(ar - Cp) = (2r)^2 t = \tfrac{2}{3} v \sqrt{C^2 + \tfrac{8}{5} v^2}.$$

Note 1.—When the segment is greater

than a semicircle, find the area of the remaining segment, and subtract from the whole area of the circle for the required area.

Note 2.—The first rule or formula gives an approximate value of the area, not very far from the truth; the last formula is still nearer the truth; and the second rule or formula may be considered as exactly true.

First find C D and A C from the properties of the figure, and the length of the arc A C B by Prob. IX.; then find the area by Rule I.; thus $DE = \sqrt{AE^2 - AD^2} = \sqrt{10^2 - 6^2} = 8$, $CD = CE - DE = 10 - 8 = 2$, and $AC = \sqrt{AD^2 + CD^2} = \sqrt{6^2 + 2^2} = 6{\cdot}324555$; whence $\frac{6{\cdot}324555 \times 8 - 12}{3} = 38{\cdot}59644$ = arc A C B, and by Rule I., $\frac{1}{2}(38{\cdot}59644 \times 10) - \frac{1}{2}(12 \times 8) = 16{\cdot}3274$ *square feet. Ans.*

By Rule II. The example being the same as before, we have C D equal to 2; and the diameter 20.

Then 20) 2 (·1
And to ·1 answers . . ·040875 per Table I.
Square of diameter . . 400

Ans. 16·3500 *square feet.*

By the third formula, the same example being still used, $A = \frac{2}{3} v \sqrt{C^2 + \frac{8}{5} v^2} = \frac{4}{3}\sqrt{12^2 + \frac{8}{5}\, 2^2} = 16{\cdot}3511$ square feet, ~~which is~~ very near the truth.

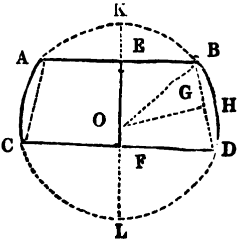
2. What is the area of the segment, the height of which is 2, and the chord 20 feet? *Ans.* 26·36046.

Problem XII.

Rule.—The zone being first divided into a trapezoid (A B C D) and two equal segments (B H D and A C), find the area of the trapezoid by Prob. III., and the areas of the two segments by Prob. XI.; which areas, being added ogether, will give the area of the zone.

1. The breadth of a zone is 42 feet, and its parallel chords are 48 and 36 feet, required the area.

The diameter, K L, is found by Prob. VIII., Baker's "Mensuration," WEALE'S series, after which the area is found by the Rule just given.



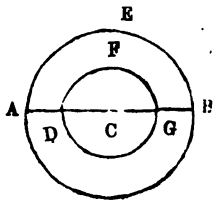
2. The two parallel chords of a zone are each 100 feet, and the radius of the circle 72 feet; required the area of the zone. *Ans.* 13508½ *square feet.*

PROBLEM XIII.

To find the area of a circular ring, or the space included between two concentric circles.

1. The diameters of the two concentric circles being A B 20, and D G 12 feet, required the area of the ring contained between their circumferences A E B A, and D F G D.

A C = 10	3·1416
D C = 6	64
sum 16	12·5664
dif. 4	188·496
64	201·0624

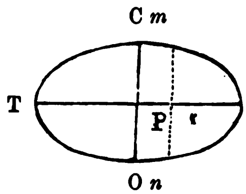


2. The diameters of two concentric circles being 20 and 10 feet; required the area of the ring between their circumferences. *Ans.* 235·72 *square feet.*

PROBLEM XIV.

To find the area of an ellipse.

RULE.—Multiply the product of the semiaxes T P, C P, by 3·1416 for the area.



1. The axes of an elliptical shrubbery in a park are 300 and 200 feet; required the area.

$$150 \times 100 \times 3{\cdot}1416 \div 9 = 5236 \text{ square yards}$$
$$= 1 \textit{ acre } 396 \textit{ square yards.}$$

2. Required the area of an ellipse, the axes of which are 70 and 50 yards. *Ans.* 2748 *square yards* 8 *feet.*

PROBLEM XV.

To find the area of an elliptical segment, the chord of which is parallel to one of the axes. (See last figure.)

RULE.—Divide the height of the segment by that axis of the ellipse of which it is a part; and find in the Table a circular segment having the same versed sine as the quotient. Then multiply continually together this segment and the two axes, for the area required.

1. *What is the* area of an elliptic segment *m* R *n*, whose *height R r is 20;* the transverse T R being 70, and the con-*jugate C O 50* feet?

70) 20 (·285$\frac{5}{7}$ the tabular versed sine.
The corresponding segment
is ·185166
70

12·961620
50

648·081000 *square feet*, the area required.

2. What is the area of the elliptical segment cut off parallel to the longer axis, the height being 5, and the axes 25 and 35 feet? *Ans.* 97·8458 *square feet.*

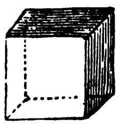
MENSURATION OF SOLIDS.

PROBLEM I.

To find the solidity of a cube.

RULE.—Cube one of its sides for the content; that is, multiply the side by itself, and that product by the side again.

1. If the side of a cube be 24 inches, what is its solidity or content?



$$\begin{array}{r} 24 \\ 24 \\ \hline 576 \\ 24 \\ \hline 13824 \end{array}\ \textit{Ans.}$$

2. How many solid yards are in a cube, the side of which is 22 feet?

$22 \times 22 \times 22 \div 27 = 394$ *solid yards* 10 *feet*. *Ans.*

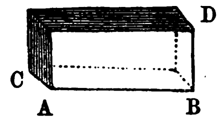
PROBLEM II.

To find the solidity of a parallelopipedon.

RULE.—Multiply the length, breadth, and depth all continually together, for the solidity.

1. Required the content of the parallelopipedon, whose length A B is 6 feet, its breadth A C $2\frac{1}{2}$ feet, and altitude *B D* $1\frac{3}{4}$ *feet*?

$$\begin{array}{r l}
1{\cdot}75 & = BD \\
6 & = AB \\
\hline
10{\cdot}50 & \\
2{\cdot}5 & = AC \\
\hline
5250 & \\
2100 & \\
\hline
26{\cdot}250 & \textit{Ans.}
\end{array}$$



2. Required the content of a parallelopipedon, the length of which is 10·5, breadth 4·2, and height 3·4.

Ans. 149·94.

3. How many cubic feet are in a block of marble, the length of which is 3 feet 2 inches, breadth 2 feet 8 inches, and depth 2 feet 6 inches? *Ans.* $21\frac{1}{9}$.

PROBLEM III.

To find the solidity of any prism or cylinder.

RULE.—Find the area of the base or end; which multiply by the height or length; and the product will be the content.

To find the area of the surface of a prism or cylinder.

RULE.—Multiply the circumference of the base or end by the length or height, and the product will be the area required.

Note.—If the *whole* surface be required, the area of the two ends must be added to the area found by the rule.

1. Required the content of a triangular prism, the length A C of which is 12 feet, and each side of its equilateral base $2\frac{1}{2}$ feet.

By the Rule ·433013 tab. No.
$6\frac{1}{4} = (2\frac{1}{2})^2$

C A

2·598078
108253

2·706331 area of end
12 length

Ans. 32·475972 *solid feet.*

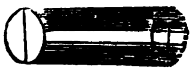
2. What is the content of a hexagonal prism, the length being 8 feet, and each side of its end 1 foot 6 inches?

Ans. 46·765 *cubic feet.*

3. Required the content of a cylinder, the length of which is 20 feet, and the circumference $5\frac{1}{2}$ feet.

$(5\frac{1}{2})^2 \times 20 \times \cdot 07958 = 48 \cdot 146$ *cubic feet.*

4. What is the convex surface of a cylinder, the length of which is 16 feet, and its diameter 2 feet 3 inches?



$3 \cdot 1416 \times 2\frac{1}{4} \times 16 = 113 \cdot 0976$ *sq. feet.*

5. How many cubic feet of stone is there in a round pillar, the height of which is 16 feet, and diameter $2\frac{1}{4}$ feet?

$(2\frac{1}{4})^2 \times 16 \times \cdot 7854 = 63 \cdot 62$ *cubic feet.*

6. How many square yards of painting are there in the convex surface of a column, the length of which is 20 feet, and its diameter 2 feet?

$2 \times 3 \cdot 1416 \times 20 \div 9 = 13$ *square yards* $8\frac{2}{3}$ *feet nearly.*

Problem IV.

To find the solidity of any cone or pyramid.

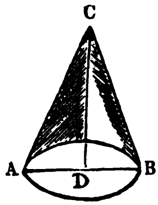
Rule.—Find the area of the base, then multiply that area by the height, and take $\frac{1}{3}$ of the product for the *solidity.*

To find the convex surface of a right cone, or the slant surface of a right pyramid.

RULE.—Multiply the circumference of the base by the slant height, or length of the side, and take half the product for the surface.

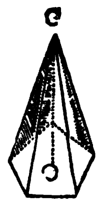
1. What is the solidity of a cone, the height C D of which is 12½ feet, and the diameter A B of the base 2½ feet?

·7854
6¼
———
4·7124
19635
———
4·90875 area of base
12½ height C D
———
58·90500
2·454375
———
3)61·359375
20·453125 *Ans.*



2. What is the solid content of a pentagonal pyramid, its height being 12 feet, and each side of its base 2 feet?

1·720477 tab. area
4 square side
———
6·881908 area base
4 $= \frac{1}{3}$ of height C O
———
Ans. 27·527632 *cubic feet.*



3. What is the content of a hexagonal pyramid, the height being 6·4, and each side of its base 6 inches?

Ans. 1·38 *cubic feet.*

4. Required the weight of a hexagonal pyramid of marble, each side of the base of which is 1 foot 3 inches, and the

vertical height 10 feet, the weight of the marble being 170 lbs. per cubic foot. *Ans.* 1 *ton* 0 *cwt.* 18½ *lbs.*

5. What is the convex surface of a cone, the slant height of which is 20, and the circumference of its base 9 feet?

$$20 \times 9 \div 2 = 180 \div 2 = 90 \textit{ square feet.}$$

6. If the diameter of the base A B be 5 feet, and the side of the cone A C 18, required the convex surface.

$$\begin{array}{rl} 3{\cdot}1416 & \\ 5 & \text{diameter} \\ \hline 15{\cdot}7080 & \text{circumference} \\ 18 & \\ \hline 125664 & \\ 15708 & \\ \hline 2)282{\cdot}744 & \\ \textit{Ans.}\ 141{\cdot}372 & \textit{square feet.} \end{array}$$

Problem V.

To find the content of the frustum of a cone, or of any pyramid.

Rule.—To the sum of the squares of the radii of the ends, if a cone, or of the sides of the ends, if a pyramid, add their product, and multiply the sum by 3·1416, if a cone, or by the tabular number of the polygon, if a pyramid, and again by ⅓ of the height for the content.

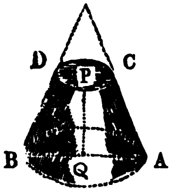
To find the convex surface of a frustum of a cone, or the slant surface of a pyramid.

Rule.—Multiply the sum of the circumferences of the two ends by ½ the slant height of the frustum for the required surface.

Note.—When the *whole* surface is required, the areas of the two *ends must be* added to the result of the Rule.

1. What is the content of a frustum of a cone, the height of which is 20 inches, and the diameter of its two ends 28 and 20 inches?

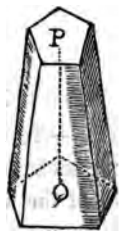
```
 28      28      20
 28      20      20
----    ----    ----
224     560     400
56      784     ----
----    400
784     ----
----    1744
        ·2618 = 1/12 of 3·1416
       ------
       13952
       1744
      10464
      3488
     --------
     456·5792
           20 = P Q
     --------
```



Ans. 9131·5840 *solid inches.*

2. Required the content of a pentagonal frustum, the height of which is 5 feet, each side of the base 1 foot 6 inches, and each side of the less end 6 inches.

```
 18      18      6
 18       6      6
----    ----    --
144     108     36
18      324     --
----     36
324     ----
----   3)468
        ----
        156 1/3 of sum
   1·720477 tab. area
   ----------
   10322862
   8602385
  1720477
  -----------
  268·394412 mean area
```




```
                 268 394412 mean area
                          5 height P Q
                 -------------
     {12 |  1341·972060
 144 {   |   111·831005
     {12 |     9·319250
```

Ans. in cubic ft.
0 2

3. How many solid feet are in a piece of timber, whose ends are squares, the sides of which are 15 and 6 inches, and the length 24 feet? *Ans.* 19½ *cubic feet.*

4. The sides of the ends of the frustum of a square pyramid are 6 and 4 feet, and its slant length 20 feet, required its slant surface.

$$\left.\begin{array}{l} 6 \times 4 = 24 \\ 4 \times 4 = 16 \end{array}\right\} \text{circumf. of ends}$$

$$\begin{array}{r} 40 \text{ sum} \\ 10 = \tfrac{1}{2} \text{ length} \\ \hline 9)400 \\ \hline 44\tfrac{4}{9} \textit{ square yards.} \end{array}$$

Note.—The slant length is measured from the middle of one side to that of its corresponding side.

5. The slant height of a tower, in the form of a hexagonal pyramid, is 74 feet, each side of the base 7½, each side of the top 2½ feet; required the area of the sides, and the expense of painting it at 1*s.* 3*d.* per square yard.

Ans. 2220 *square feet, and* £15 8*s.* 4*d.*

Problem VI.

To find the solidity of a wedge.

Rule.—To the length of the edge add twice the length of the back or base, and reserve the sum; multiply the height of the wedge by the breadth of the base; then multiply the product by the reserved sum, and take $\frac{1}{6}$ of the last product for the content.

1. What is the content in feet of a wedge, the altitude A P of which is 14 inches, its edge A B 21 inches, and the length of the base D E 32 inches, and its breadth C D 4½ inches?

21	14
32	$4\frac{1}{2}$
32	—
—	56
85	7
—	—
	63
	85
	315
	504

Note.—The student readily can draw the figure, or refer to page 64, Baker's "Mensuration," WEALE's Series.

$$
\begin{array}{r|l}
6 & 5355 \\
1728\left\{\begin{array}{r}12\\12\\12\end{array}\right. & \begin{array}{l}892\cdot5 \text{ \textit{Ans. in cubic inches}}\\ \;\;74\cdot375\\ \;\;\;\;6\cdot197916\end{array} \\
 & \;\;\;\;\;\;\cdot516493 \text{ \textit{Ans. in cubic feet, or little more than half a cubic foot.}}
\end{array}
$$

2. The edge and base of a wedge are respectively 9 feet and 5 feet 4 inches in length, the base is 2 feet 8 inches in breadth, and the height $3\frac{1}{2}$ feet; required the content of the wedge. *Ans.* 30 *cubic feet* 7′ 1″ 4‴.

PROBLEM VII.

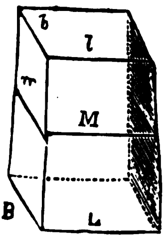
To find the solidity of a prismoid.

Definition.—The ends of a prismoid are parallel and dissimilar rectangles or trapezoids; the solid is, therefore, the frustum of a wedge, the part of the wedge next the edge being cut off.

RULE.—Add into one sum the areas of the two ends, and 4 times the middle section parallel to them, and $\frac{1}{6}$ of that sum will be a mean area; which being multiplied by the height, will give the content.

Note.—For the length of the middle section, take half the sum of the lengths of the two ends; and for its breadth, take half the sum of the breadths of the two ends.

1. How many cubic feet are there in a stone, the ends of which are rectangles, the length and breadth of the one being 14 and 12 inches, and the corresponding sides of the other 6 and 4 inches; the perpendicular height being 30½ feet?




```
 14        10        6
 12         8        4
 ---       ---      ---
168        80       24
---         4       ---
          ---
          320
          168
           24
          ---
        5)512
          ---
          85⅓ mean area in inches
          30½ height
          ----
         2560
           42⅔
         -----
144 {12 | 2602·6̇
    {12 |  216·8̇
        |   18·07̇4̇ Ans.
```

2. What is the content of a railway coal waggon, of which the length and breadth at top are 81½ and 55 inches, at bottom the length and breadth are 41 and 29½ inches, and the height 47½ inches? *Ans.* 73⅓ *cubic feet.*

Problem VIII.

To find the solidity of a sphere or globe.

Rule.—Multiply the cube of the diameter by ·5236.

1. The diameter of a sphere is 12 feet; required its solidity.

$12^3 \times \cdot 5236 = 904\cdot 7808$ *cubic feet.*

2. Find the content and weight of an ivory ball $3\frac{1}{2}$ inches in diameter, the weight of ivory being 1820 ounces (Av.) per cubic foot.

Ans. Content 22·448 *cub. in., and weight* 24 *oz. nearly.*

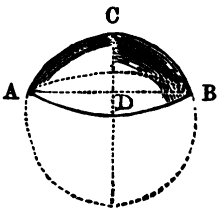
Problem IX.

To find the solidity of a spherical segment.

Rule.—To three times the square of the radius of the base, add the square of the height; multiply the sum by the height, and the product again by ·5236.

1. Required the content of a spherical segment, its height being 4 inches, and the radius of its base 8.

8	4	·5236
8	4	832
64	16	10472
3	192	15708
		41888
192	208	
	4	435·6352 *Ans.*
	832	



2. What is the solidity of the segment of a sphere, the height of which is 9, and the diameter of its base 20 feet?

Ans. 1795·4244 *cubic feet.*

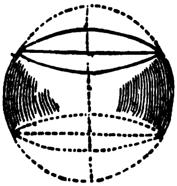
Problem X.

To find the solidity of a spherical zone or frustum.

Rule.—Add together the squares of the radii of the

ends, and $\frac{1}{3}$ of the square of their distance or height; multiply the sum by the said height, and the product again by 1·5708.

1. What is the solid content of a zone, its greater diameter being 12 inches, the less 8, and the height 10 inches?



$$6^2 = 36$$
$$4^2 = 16$$
$$\tfrac{1}{3} \times 10^2 = 33\tfrac{1}{3}$$
$$85\tfrac{1}{3}$$

$85\frac{1}{3} \times 10 \times 1{\cdot}5708 = 1340{\cdot}416$ *cubic in.*, the content required.

2. Required the content of a zone; the great diameter is 12, less diameter 10, and height 2 feet.

Ans. 195·8264 *cubic feet.*

3. A cask is in the form of the middle zone of a sphere, its top and bottom diameters being 5 feet 8 inches, and its height 5 feet, inside measure; how many gallons will it contain? *Ans.* 1193$\frac{3}{4}$ *gallons.*

Problem XI.

To find the convex surface of a sphere, also of a segment and zone thereof.

For the sphere.

Rule.—Multiply the square of the diameter by 3·1416.

For the segment or zone.

Rule.—Multiply the circumference of the whole sphere by the height of the segment or zone.

1. Required the convex surface of a sphere, the diameter of which is 2 feet.

$2^2 \times 3{\cdot}1416 = 12{\cdot}4264$ *square feet, Ans.*

2. The circumference of a spherical stone is 4 feet; required its convex surface.

$$4^2 \div 3{\cdot}1416 = 5{\cdot}0928 \textit{ square feet.}$$

3. The axis of a sphere being 42 inches, what is the convex superficies of the segment, whose height is 9 inches?

$$42 \times 9 \times 3{\cdot}1416 = 1187{\cdot}5248 \textit{ square inches.}$$

4. Required the convex surface of a spherical zone, the height of which is 2 feet, and cut from a sphere of $12\frac{1}{2}$ feet diameter.

$$12\tfrac{1}{2} \times 2 \times 3{\cdot}1416 = 78{\cdot}54 \textit{ square feet.}$$

Problem XII.

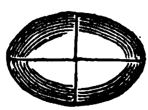
To find the solidity of a spheroid.

Rule.—Square the revolving axis; multiply that square by the fixed axis, and again by ·5236 for the solidity.

Note.—In the prolate spheroid, the revolving axis is the conjugate; but, in the oblate, the revolving axis is the transverse.

1. Required the solidity of a prolate spheroid, the axes being 50 and 30 inches.

30	·5236
30	45000
900	26180000
50	20944
45000	23562·0000 *Ans. cub. in.*



2. Required the content of an oblate spheroid, whose axes are 50 and 30 inches.

Ans. 22·7257 cubic feet.

Problem XIII.

General rule for finding the contents of solids.

The wedge, the prismoid; the cone, all pyramids, and their frustums; the whole or a segment, or any portion of the whole, contained between two parallel planes perpendicular to the axis of a sphere, of an ellipsoid, of a paraboloid, of a hyperboloid, may be found by the following general formula.

Let A and B be the areas of the ends of the solid, C the area of the section parallel to and equidistant from the ends, and L the perpendicular distance between the ends; then

$$\text{The solidity} = \frac{A + B + 4C}{6} \times L.$$

The investigation of this very general Rule was given by B. Gompertz, Esq., F.R.S., &c., in the "Gentleman's Mathematical Companion" for 1822; see also Baker's "Mensuration," p. 135, where the investigation is also given.

DIVISION II.

LAND SURVEYING.

THE CHAIN, usually called Gunter's Chain, is almost generally used in the British dominions for measuring the distances required in a survey. It is 66 feet, or 4 poles, in length, and is divided into 100 links, which are joined by rings. The length of each link, together with half the rings connecting it with the adjoining links, is, consequently, $\frac{66}{100}$ of a foot, or $\frac{66\times12}{100}=7\cdot92$ inches.

THE OFF-SET STAFF is used to measure short distances, called off-sets. It is usually 10 links in length, the links being numbered thereon by the figs. 1, 2, 3, &c. It is usually pointed with iron at one end, for the purpose of fixing it in the ground, for ranging lines and marking stations.

THE CROSS is an instrument used by surveyors to erect perpendiculars. It is usually a round piece of sycamore, or mahogany, about 4 inches in diameter, with two folding sights at right angles to each other, or more commonly with two fine grooves at right angles to each other, which answer the purpose of sights. It is commonly fixed on a staff of convenient length for use, pointed with iron at the bottom, that it may be fixed firmly in the ground.

For further directions for Measuring Lines on the

Ground, the descriptions of Instruments for planning Surveys, and the Method of keeping the Field-book, see Baker's "Land and Engineering Surveying," WEALE's series.

A TABLE OF LINEAR MEASURE.

Links.	Feet.	Yards.	Poles.	Chains.	Furlongs.	Mile.
25	16½	5½	1			
100	66	22	4	1		
1,000	660	220	40	10	1	
8,000	5,280	1,760	320	80	8	1

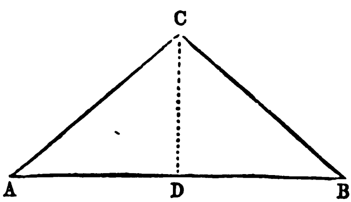
A TABLE OF SQUARE MEASURE.

Sq. Links.	Sq. Feet.	Sq. Yards.	Sq. Poles or Perches	Sq. Chs.	Rods.	Acres.	Sq. Mile.
625	272¼	30¼	1				
10,000	4,356	484	16	1			
25,000	10,890	1,210	40	2½	1		
100,000	43,560	4,840	160	10	4	1	
64,000,000	2,787,400	3,097,600	102,400	6,400	2,560	640	1

Triangular Fields.

1. Let A B C be a triangle, of which the survey, plan, and content are required.

Set up poles or marks at the angles A, B, and C, and measure from A towards B, and when at or near D, try with the cross for the place of the perpendicular C D; plant the cross, and turn it till the marks A and B can be seen



through one of the grooves; then look through the *other groove, and, if* the mark at C can be seen through it,

the cross is in the right place for the perpendicular; if not, move the cross backward or forward till the three marks can be seen as before directed. Suppose the distance A D to be 625 links, and the whole A B, to be 1257 links; return to D, and measure the perpendicular D C, which suppose to be 628 links, thus completing the survey of the triangle.

1. The dimensions being the same as those given above, required the area of the triangle.

$1257 \times 628 \div 2 = 3{\cdot}94698$ *acres* $= 3a.\ 3r.\ 32p.$ *Ans.*

2. The base of a triangle is 954 links, and the perpendicular 246; required the area of the triangle.

$954 \times 246 \div 2 = 1{\cdot}17342 = 1a.\ 0r.\ 27\frac{1}{2}p.$ *Ans.*

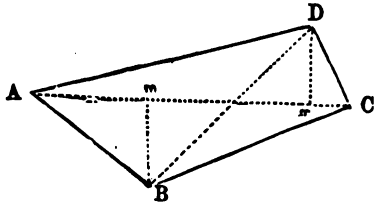
Fields in the form of trapeziums.

Fields in this form are usually divided into two triangles by a diagonal, which is a base to both triangles.

Let A B C D be a field of this form. Measure from A towards C, and let the place of the perpendicular *m* B be at 5·52 links, and its length 3·76; also let the place of the perpendicular *n* D be at 11·82, and its length 3·44, and the length of the whole diagonal A C be 13·91, which completes the survey; but it is also usual to measure the other diagonal B D for a proof line, which is found to be 9·56.

Note. The rule for finding the area is the same as that given in Prob. IV.

1. Let the measurement of a trapezium be as above found; required the content.



$$
\begin{array}{r}
344 \\
376 \\
\hline
720 \\
1391 \\
\hline
27820 \\
9737 \\
\hline
2)10{\cdot}01520 \\
\hline
5{\cdot}00760 \\
4 \\
\hline
0{\cdot}03040 \\
40 \\
\hline
1{\cdot}21600
\end{array}
$$

Ans. 5*a.* 0*r.* 1*p.*

2. From the following Notes to Plan find the content of a field.

Perpendiculars on left.	Base or Station Line.	Perpendiculars on right.
	to ⊙ C	
	3250	
	2504	1046 D
B 1278	1272	
Begin	at ⊙ A	and range West.

Content. 37*a.* 3*r.* 2*p.*

To survey fields contained by more than four sides.

Fields, or plots of ground, bounded by more than four sides, may be surveyed by dividing them into trapeziums and triangles.

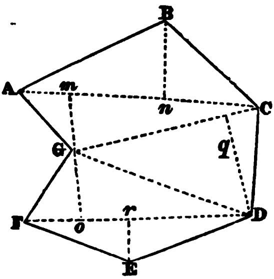
To find the content.

Rule.—By the preceding Problems, find the double areas

of each trapezium and triangle in the field; add all the double areas together, and half their sum will be the content.

1. Lay down a field and find its area from the following dimensions:

	to ⊙ D	
	520	
p	288	80 E
G 120	206	*o*
	Go to ⊙ F	
	to ⊙ G	
	440	
D 230	152	*q*
	L. of ⊙ C	
	to ⊙ C	
	550	
B 180	410	*n*
m	135	130 G
Begin	at ⊙ A	range E.



For the method of planning this field, see Baker's "Land and Engineering Surveying," Weale's series, p. 21.

130	440	120	Double areas.
180	230	80	170500 trap. A B C G
			101200 tri. C D G
310	13200	200	104000 trap. D E F G
550	880	520	
			2)3·75700
15500	101200	104000	
1550			1·87850 = 1*a*. 3*r*. 20½*p*.
170500			

To find the areas of irregular figures, whether bounded by straight lines or curves.

Case I.—When the figure is long and narrow.

Rule I.—Find the areas of all the trapezoids and triangles separately, and add them together for the area.

RULE II.—Add all the breadths, and divide the sum by the whole number of them for the mean breadth, which multiply by the length for the area. This method is not very correct, but may do where great accuracy is not required.

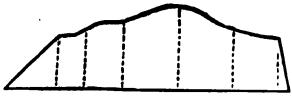
RULE III.—Take the perpendicular breadth, at several places, at equal distances; to half the sum of the first and last breadths add all the intermediate, and multiply the result by the common distance between the breadths for the area.

1. The breadths or offsets of an irregular figure, at five equidistant places, are $AD = 8{\cdot}2$, $mp = 7{\cdot}4$, $nq = 9{\cdot}2$, $or = 10{\cdot}2$, $BC = 8{\cdot}6$ feet, and the common distance $Am = mn = \&c. = 50$ feet; required the area.

By Rule III.

$$\begin{array}{r l} 8{\cdot}2 & \\ 8{\cdot}6 & \\ \hline 2)16{\cdot}8 & = \text{sum} \\ \hline 8{\cdot}4 & = \tfrac{1}{2}\text{ sum} \\ 7{\cdot}4 & \\ 9{\cdot}2 & \\ 10{\cdot}2 & \\ \hline 35{\cdot}2 & \\ 50 & \\ \hline \end{array}$$

Ans. 1760·0 *square feet.*



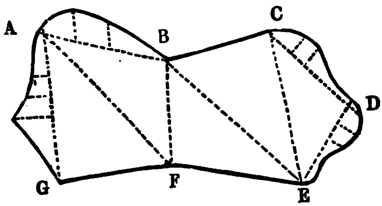
2. Take the dimensions and find the area of the annexed irregular figure, by Rules I. and II.

CASE II.—When the breadth of the figure is large, and its boundary curved or crooked.

RULE.—Divide the figure into trapeziums and triangles, *the most convenient* manner, taking offsets to the curved

or crooked portion of the boundary. Find the areas of the trapeziums, triangles, and the offset pieces separately, which being added together, will give the required area of the whole figure.

The annexed figure is divided into two trapeziums, A B F G, B C E F, and one triangle, C D E, with offsets on A B, A G, C D, and D E. It is required to measure the several parts of the figure, and to find its area.



The areas of the trapeziums are found by letting fall perpendiculars on the diagonals A F, B E, by Problem IV., and the area of the triangle by Problem II., the areas of the several offset pieces being found by one or other of the preceding rules.

For further information concerning extensive surveys of parishes, manors, large estates, &c., &c., the reader is referred to Baker's "Land and Engineering Surveying," in the series, in which is given an *engraved field-book and its accompanying plan*, and in which is also given numerous specimens of *surveys for railways*, both by the chain only, and with the help of the theodolite. This part of the work concludes with extensive directions for dividing land and commons of variable value among their several claimants in proportion to the value of their claims.

DIVISION III.

ENGINEERING SURVEYING.

LEVELLING.

By the art of levelling, the inequalities of the upper boundary of any section of the earth's surface may be shown, and thence may be determined the several heights of any number of points in that boundary above or below an assumed line, called a level line; though this line, in reality, is a great circle of the earth, and is such as would be derived from a section of the surface of still water.

Levelling Instruments.

1. Levelling instruments all depend on the action of gravity; of these the plumb-line, on which the mason's level depends, is the most simple, but it cannot be used in extensive operations, on account of its practical inconvenience. The fluid, or water level, in all its modifications, is also found inconvenient for extensive practice.

2. Spirit levels are now commonly used, as the most accurate instruments for finding the differences of level, or vertical distances between two stations.

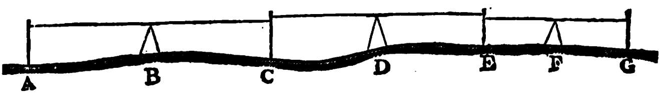
The Y *level*, *Troughton's level*, and *Gravatt's level*, which is also called the *Dumpy*, are the most commonly used, especially the last named one. Descriptions of these instruments, and the methods of adjusting them, are given in Baker's "Land and Engineering Surveying," in the

series, in which is also given a description of *Gravatt's levelling staves*, which are now most commonly used.

PRINCIPLES AND PRACTICE OF LEVELLING.

To find the difference of the levels of several points on the surface of the earth.

1. Let it be required to find the difference of level between the points A and G. A levelling staff is erected at A, the instrument is set up and adjusted at B, another staff is also erected at C, at the same distance from B that B is from A, as nearly as can be judged by the eye; the reading of the two staves are then noted; the horizontal lines, connecting the staves with the instrument, represent the visual ray or level line of sight; the instrument is then conveyed to D, and the staff tha stood at A is now removed to E, the staff C retaining its former position, only its graduated side turned to the instrument, and from being the fore staff at the last observation, it is now the back staff; the reading of the two staves are again noted, and the instrument removed to F, and the staff C to the point G, the staff at E retaining its position, now in its turn becomes the back staff, and so on to the end of the work, which may thus be continued to any extent. The difference of the readings of the staves at A and C will show the difference of level between the points or stations A and C, because the visual line of the instrument is virtually level, and the same is true with respect to every two consecutive stations.



EXAMPLE.

Back sight on staff A	10·66 feet
Fore sight on staff C	11·78 "
The fall from A to C	1·12 difference.

Because when the front reading is the greater, the ground falls, and *vice versâ*.

Back sight on staff C	13·36 feet
Fore sight on staff E	9·16 "
The rise from C to E	4·20 difference.
Subtract the fall from A to C	1·12
The rise from A to E	3·08 difference.

By proceeding in this manner through two more similar operations, we shall find the total rise from A to G to be 2·54 feet, or nearly 2 feet 6½ inches.

The difference of the sums of the back and fore reading of the staves will more readily give the difference of level between A and G; thus:—

Back Sights.	Fore Sights.
feet	feet
10·66 at A	11·78 at C
13·36 at C	9·16 at E
7·62 at E	8·16 at G
sums 31·64	29·10
29·10	
2·54 difference of level.	

To draw a sectional line of several points on the earth's surface, the levels of which have been taken.

Let a b c d e f and g be the several points; then, in order to draw the section to show the undulations of the

ground between a and g, the distances of the several points from a, in addition to their levels, must be taken; this is usually done during the operation of levelling. These distances with the back and fore sights, may be arranged in a level book of the following form, which, though not the form practically used, will probably be more clearly understood. (See fig. page 47).

LEVEL BOOK.

Back Sights.	Fore Sights.	Fall.	Rise.	Reduced Levels.	Distances in Chains, and Remarks.
3·50	5·65	2·15		2·15	4·60 at b on road.
4·10	10·85	6·75		8·90	7·80 at c.
5·04	9·25	4·21		13·11	11·60 at d.
3·84	12·91	9·07		22·18	15·20 at e.
4·12	7·65	3·53		25·71	bottom of canal, distance 2·16.
10·49	3·92		6·57	19·14	21·00 at f.
12·96	3·03		9·93	9·21	27·00 at g.
44·05	53·26				
	44·05				
diff.	9·21	the same as the last of the reduced levels.			

In this level book it will be seen that the differences 2·15 and 6·75, in the column marked Fall, are added together making 8·90 thus giving the fall at c, in the column marked Reduced Levels: to this sum the succeeding falls are added, one by one, till we get the fall 25·71 at the bottom of the canal, which is the lowest point. Then the differences in the column marked Rise are subtracted successively from 25·71 for the falls at f and g; the latter of which is 9·21, the total fall from a to g, which, agreeing with the difference of the sums of the back and fore sights, shows the truth of the castings. The last column shows the distances of the

several points, *b*, *c*, &c., from *a*, in chains, with other remarks.

DATUM LINE.

The section might be plotted by laying off the distances in the last column in the preceding level book on a horizontal line, and setting off their corresponding numbers of feet, in the column marked Reduced Levels, perpendicularly below the line; but it is found inconvenient in practice to plot a section in all cases after this method, as in extensive operations the reduced levels would repeatedly fall above and below the line in question, and thus confuse the operation; therefore a line A G, called the "datum line," is assumed at 100, 200 feet, &c., below the first station *a*; thus making that line always below the sectional line *a f*, of which a clearer view may be obtained.

In the following practical level book the rise and fall are respectively added to or subtracted from the assumed distance of the datum line, and the next rise or fall again added to or subtracted from the sum or difference:—thus, 2·15, being a fall, is subtracted from 100 (the assumed distance of the datum line), leaving 97·85 feet, the height of the ground at *b*; the next fall: 6·75, is then subtracted from 97·85, leaving 91·10 feet for the height at *c*; and so on to 3·53, which is the last fall; the next, 6·57, being a rise, is added, as well as 9·93. Thus the last reduced level is 90·79 feet, which taken from the datum, 100, leaves 9·21 feet, agreeing with the differences of the sums of the back and fore sights, and of the sums of the rises and falls, and showing the work of casting to be correct. Thus are obtained a series of vertical heights, to be set off perpendicularly to the datum line, through the upper extremities of which the sectional line must be drawn.

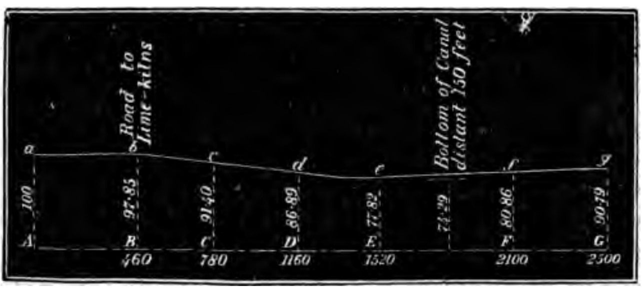
PRACTICAL LEVEL BOOK.

(Datum line 100 feet below the bench mark at A.)

Back Sights.	Fore Sights.	Rise.	Fall.	Reduced Levels.	Distances.	Remarks.
feet.	feet.	feet.	feet.	feet.	chains.	
				100·00 D		
3·50	5·65		2·15	97·85	4·60	B M on road to lime kilns.
4·10	10·85		6·75	91·10	7·80	
5·04	9·25		4·21	86·89	11·60	
3·84	12·91		9·07	77·82	15·20	Bottom of canal, distant 2·80 chains.
4·12	7·65		3·53	74·29	......	
10·49	3·92	6·57		80·86	21·00	
12·96	3·03	9·93		90·79	27·00	to B M at *g*.
44·05	53·26	16·50	25·71	100·00		
	44·05		16·50			
	9·21	diff. =	9·21 =	9·21	diff. between last reduced level and datum.	

In laying down the sectional line from the above columns of reduced levels and distances, the former are always taken from a much larger scale than the latter, otherwise the undulations on the surface of the ground would in many cases be hardly perceptible.

Draw the horizontal line A G, setting off the distances



A B, A C, &c., as in the column of distances, that is A B = 4·60 chains, A C = 7·80, &c., then draw A a = 100

feet; perpendicular to A G and parallel to A *a* draw B *b*, C *c*, &c., setting off their heights 97·85, 91·10, &c., respectively; from the column of reduced levels, and through the points *a*, *b*, *c*, &c., draw the required sectional line *a g*.

LEVELS FOR THE FORMATION OF A SECTION.

In this case it is required to take the levels of a line of country, where the ground plan is already made, and the line of section determined upon and marked out on the plan. Here, in addition to what is required in running or check levels, the distances to the several stations of the levelling staves from the starting point must be measured.

Two additional assistants are required in this case to measure the distances of the stave stations along the lines, while the operation of levelling goes on, which is the same in every respect as that already described, excepting that, in this case, the operation is conducted upon a line, on the surface plan, a copy of which must be in the surveyor's possession to direct him, and the distances of the several stave stations must be noted in the level book, in the column marked "Distances."

The following is the level book of an example, showing the manner of keeping it, and also the method of reducing the levels, to obtain the actual heights of each station above the datum line, which is placed 100 feet below the starting point, for convenience of drawing the section. The whole operation being similar to that already given at page 47, excepting that here we give the particular manner of performing the several parts of the field work, in order that it may be clearly understood by those who are unacquainted with the subject, as it is presumed that, in a short time, railways will become the common means of transit, both for

for passengers and goods, throughout every country of the civilised world.

THE LEVEL BOOK FOR PLOTTING THE SECTION.

(Datum 100 feet below the station A.)

Back Sights.	Fore Sights.	Rise.	Fall.	Reduced Levels.	Distances.	Remarks.
feet.	feet.	feet.	feet.	feet.	links.	
				100·00 D		
13·71	7·88	5·83		105·83	519	B. M. side of road.
9·40	16·30		6·90	98·93	1315	
3·87	11·71		7·84	91·09	1542	
2·63	12·41		9·78	81·31	1850	
14·62	0·95	13·67		94·98	2358	
17·00	1·45	15·55		110·53	2698	
10·66	15·40		4·74	105·79	3357	
2·87	17·00		14·13	91·66	3758	
3·40	10·32		6·92	84·74	3976	
5·73	2·24	3·49		88·23	5077	
16·54	0·85	15·69		103·92	5904	
16·08	0·89	15·19		119·11	6124	
14·56	0·73	13·83		132·94	6437	
10·36	14·06		3·70	129·26	7467	
9·84	1·36	8·48		137·72	8369	
9·80	7·00	2·80		140·52	9303	
2·30	10·96		8·66	131·86	—	Centre of road at [215 links.
10·96	14·46		3·50	128·36	9679	
2·08	15·05		12·97	115·39	9936	
1·75	16·58		14·83	100·56	10164	
1·84	17·10		15·26	85·30	10576	
0·00	7·43		7·43	77·87	11423	Forward ⊙ at cor- [ner of wood.
5·38	3·50	1·88		79·75	13066	
8·50	4·50	4·00		83·75	14954	
5·30	1·36	3·94		87·69	15650	
10·29	9·40	0·80		88·49	17345	
6·86	0·40	6·46		94·95	19135	
11·00	3·96	7·04		101·99	19359	
11·80	3·53	8·27		110·26	19631	
10·53	2·68	7·85		118·11	19841	Forward ⊙ at end [of wood.
8·82	1·38	6·84		124·95	20561	
8·76	2·20	6·56		131·51	21671	
14·00	14·50		0·50	131·01	—	Road at 450 links.
14·50	4·32	10·18		141·19	22710	
9·14	1·00	8·14		149·33	23221	
304·19	254·86	166·49	117·16	100·00		
254·86		117·16				
49·33	—	*49·33*	--	49·33	Difference between Datum and last Reduced Level, or height of B above A	
				D		

The several differences of the sums of the back and fore sights, of the sums of the rises and falls, and of the last reduced level and the datum, exactly agreeing, proves the accuracy of the arithmetical operation in the preceding level book, all these differences being 49·33 feet, which is the height of the last station above the first.

It is advisable for the surveyor to reduce the levels in the field as he proceeds, as it will occupy very little time, and can be easily done while the staffman is taking a new position. The surveyor will thus be enabled to detect with the eye if he is committing any glaring error; for instance, inserting a number in the column of rises, when it ought to be in that of falls, the surface of the ground at once reminding him that he is going downward instead of ascending.

It is seldom the case in practice that the instrument can be placed precisely equi-distant from the back and fore staves, on account of the inequalities of the ground, ponds, &c.; it would appear, therefore, to be necessary, to make our results perfectly correct, to apply to each observation the correction for curvature and refraction, as explained at page 118 in Baker's "Land and Engineering Surveying:" this, we believe, is seldom done unless in particular cases, where the utmost possible accuracy is required, on account of the smallness of such correction, as may be seen by referring to the table at the end of the book just referred to, where this correction for 11 chains is shown to be no more than $\frac{1}{100}$ part of a foot; and as the difference in the distances between the instrument and the fore and back staves can in no case equal that sum, it is evident that such correction may be safely disregarded in practice. Besides, it is not necessary to have the level placed directly between the *staves* while making observations, as it is frequently incon-

venient to do so for reasons just given, nor does a deviation from a line of the staves, in this respect, in the least affect the accuracy of the result.

The distances in the sixth column of the level book are assumed to be horizontal distances, and in measuring them, care should be taken that they are as nearly such as possible, or they must be afterwards reduced thereto, otherwise the section will be longer than it ought to be. For the purpose of assisting the surveyor in making the necessary reduction from the hypothenusal to the horizontal measure, when laying down the section, a table is given in Baker's "Land and Engineering Surveying," page 146, showing the reduction to be made on each chain's length for the several quantities of rise, as shown by the reading of the staves.

Note.—For extensive information on this subject, see Baker's "Land and Engineering Surveying," where an engraved plan and section, adapted to this example, are given at the end of the work.

DIVISION IV.

ON LAYING OUT A RAILWAY.—CURVES.

RAILWAY CURVES.

The natural unevenness of the earth's surface renders the use of curves in railways absolutely necessary, in order that the nearest practicable level may be secured, by avoiding mountains, crags, and other minor elevations, by winding round their bases by means of curves; which are also equally required to avoid various other natural and artificial obstructions, as rivers, lakes, sea-coasts, swamps, &c.: also towns, parks, pleasure-grounds, &c. Thus a great saving is effected in the cost of construction, and in the severance of valuable property, which would be otherwise required. Besides, winding railways are frequently required, in order that they may embrace in their routes important towns, harbours, mineral districts, &c., or make junctions with other railways.

In railway practice the curve adopted is always an arc of a circle; and sometimes two, three, or more consecutive arcs of circles of different radii, having a common tangent or tangents at their point or points of junction, as in the *compound curve.* Frequently the railway curve is composed

of two or more circular arcs, having their convexities turned in different directions, with a common tangent or tangents at their point or points of junction; a curve thus composed is called the *serpentine or* S *curve.* The straight portions of the railway are always first laid out, and are, in all cases, tangents to the curves at their *termini.*

It has been found in practice that at least four different methods of laying out railway curves on the ground are requisite, on account of obstructions on the ground, such as buildings, cliffs, woods, rivers, &c., situated either on the convex or concave side of the curve, or on both sides, or on the curve itself; also on account of pits, bogs, swamps, &c., which either wholly or partly prevent the use of the surveying chain.

Railway curve-rulers are a series of arcs of circles of various radii, usually from 3 to 60 inches, and are used for projecting railway curves on parliamentary maps, &c.; and to determine the radii of curves already projected. The radius of each curve-ruler is marked upon it in inches; and, when a curve-ruler is applied to a railway map, the scale of which is 5 chains to an inch, the radius must be multiplied by 5 to obtain the true radius of the curve: thus, if the radius of the curve-ruler be 16 inches, then $16 \times 5 = 80$ chains = one mile, which is the radius of the curve; and so on for maps of other scales.

The limit of the radii of railway curves.—By the Standing Orders of Parliament, a *minimum* limit of one mile, or 80 chains, was formerly assigned to the radii of railway curves; because, in curves of less radii, a railway-train of great velocity has a tendency to run off the line on the convex side of the curve. This limitation is now very frequently dispensed with, by giving a proper superelevation to the exterior rail of the curve to counterbalance the

centrifugal force. (See Formula for this purpose at the end of this article.)

(1.) *To lay out a railway curve by the common method.* See fig. page 163, Baker's "Land and Engineering Surveying."

Let $B q_2 q_4$ be the curve of a railway, O the centre, O B the radius, and $A B_1$ $D q_4$ tangents to curve at B and q_4, these tangents being straight portions of the line of railway which are to be joined by the curve. Having determined the radius O B, measure on the tangent A B prolonged the distance $B p_1$ = one chain; find the deflection $p_1 q_1$, of the curve from the tangent corresponding to the radius B O in a table provided for this purpose at the end of Division VI., and set it off at right angles to $B p_1$; from p_1 to q_1, through B and q_1, measure the right line $B q_1 p_2$ = two chains; and set off $p_2 q_2$ = twice $p_1 q_1$, repeating the last operation till the curve shall be completed at q_4; the last offset $p_5 q_5$, which meets the tangent $D q_4$, must be equal to the first offset $p_1 q_1$, otherwise there is an error in the operation, and it must be corrected.

If the distances $B p_1$, $q_1 p_2$, be taken 2, 3, or 4 chains, the offset $p_1 q_1$ must be taken respectively 4, 9, or 16 times, *i. e.* 2^2, 3^2, or 4^2 times the offset in the table, and consequently $p_2 q_2$ the double of $p_1 q_1$ as before. If $r = \text{B O}$, and $d = B p_1$; then $p_1 q_1 = \frac{d^2}{2r}$, and $p_2 q_2 = p_3 q_3 =$, &c. $= \frac{d^2}{r}$.

Demonstration.—Complete the semicircle $B q_3 C$, prolong B O to C, and join $q_1 C$, $B q_2$. Then, because $B p_1$, $B p_2$, $B q_2$, are always, in practice, so very small

compared with B C that they nearly coincide with the curve, $\therefore$ B p_1 is approximately $= B q_1 = q_1 p_2 = q_1 q_2 = \frac{1}{2} B q_2$; and by the nature of the circle the Δ s B q_1 C, B p_1 q_1, B p_2 q_2 are similar, and B C : B q_1 :: B q_1 : p_1 q_1 = $\frac{B q_1^2}{BC} = \frac{B p_1^2}{BC} = \frac{d^2}{2r}$, also B C : B q_1 :: B q_2 : p_2 q_2 = $\frac{2 B p_1^2}{BC} = \frac{d^2}{r}$; and when d = 1 chain, p_1 q_1 = $\frac{1}{2r}$, and $p_2 q_2 = p_3 q_3$ = &c. $\frac{1}{r}$.

Example.—When O B = 1 mile = 80 chains, p_1 q_1 = $\frac{1}{2r} = \frac{1}{160}$ of a chain $= \frac{792}{160} = 4{\cdot}95$ inches, and $\therefore$ p_2 q_2 $= 2 p_1 q_1 = 9{\cdot}9$ inches.

(2.) *To lay out a railway curve by equidistant offsets from its tangents.*

See fig. p. 165, Baker's "Land and Engineering Surveying."

Let B P C be a railway-curve, A B, D C tangents to the curve at B and C, and O B the radius: join T O: then the radius O B being determined from the map, if sufficiently accurate, or by measuring the tangents B T, T C, and taking the angle B T C; with half of which, *i. e.* $\angle$ B T O, and the side B T, the Δ B T O becomes known, and consequently the radius B O becomes known; find the offset corresponding to the radius B O in the table at the end of this article, which is the first offset $p\,q$: which set off from the tangent B T at the distance B p = 1 chain; then measure $p' p''$ = 1 chain, and lay off $p' q' = 4\, p\, q$. The successive offsets at the end of every chain, being $\frac{1}{2r}, \frac{2^2}{2r}, \frac{3^2}{2r}, \frac{4^2}{2r}$, &c., or, what amounts to the same thing,

the 2nd, 3rd, 4th, &c. offsets are respectively 2^2, 3^2, 4^2, &c, times the offset, or 4, 9, 16, &c., times the first one. This operation must be repeated in C T.

Demonstration.—Draw the radius q' O, and $q' a \perp$ to BO. Put B O $= q'$ O$=r$, and $q' a = p'$ B $= d$; then a O $= \sqrt{r^2 - d^2}$, and B $a = p' q' = r - \sqrt{r^2 - d^2}$. If in this formula d be taken successively $=$ 1, 2, 3, &c. chains, then values of $p\,q, p'\,q', p''q''$, &c., will be respectively $r - \sqrt{r^2 - 1^2}$, $r - \sqrt{r^2 - 2^2}$, $r - \sqrt{r^2 - 3^2}$, &c. But as 1^2, 2^2, 3^2, &c., are very small compared with r^2, within the limitation which will hereafter be assigned to this operation, the above formulæ, without material error, become respectively $p\,q = \frac{1^2}{2\,r}$, $p'\,q' = \frac{2^2}{2\,r}$, $p''\,q'' = \frac{3^2}{2\,r}$, $p'''\,q''' = \frac{4^2}{2\,r}$, &c.

Example.—Let B O$=$80 chains; then $p\,q = \frac{1 \times 792}{2 \times 80}$ $= 4{\cdot}95$ inches; whence $p'q' = 4 \times 4{\cdot}95 = 19{\cdot}8$ inches, $p''q'' = 9 \times 4{\cdot}95 = 44{\cdot}55$ inches, &c., or the value of the first offset may be taken from the table at the end of this article.

Note.—The length of tangents B T, T C, ought never to exceed ¼ of the length of the radius B O, otherwise the offsets become too long, which never ought to exceed 2 chains; and, if the curve be a long one, the tangent T C must be prolonged, and by making the prolongation beyond D, the base of an operation similar to the last, the length of the curve may be doubled; and so on to any extent.

(3.) *To correct a defective curve.*

It is sometimes found, in running out a curve from the tangent B T, that, instead of uniting with the previously determined tangent T′ C D at C, it ends tangentially in a line parallel to T′ D, either within it, as at c; or beyond it,

as at c'. Having first ascertained that no error has occurred in tracing out the curve, and that it may arise from a trifling inaccuracy in the map; besides, if the error be small, it may be proportionably divided without retracing the curve. This method may be used with perfect security where the error does not exceed 1 link in a chain. Thus, if the curve be 20 chains long, and the error C towards c be 10 feet; then m', n', o', &c., being the stumps, which mark out the defective curve, by the following proportion, there results 20 : 10 ft. :: 1 : ½ ft. = 6 inches = $m\ m'$, 20 : 10 ft. :: 2 : 1 ft. = $n\ n'$, &c. These distances being set off perpendicularly to the curve B c, at the end of each chain, up to the 19th chain, will give the points m, n, o, &c. in the corrected curve B C; if the curve fall beyond C, as at c', the distances previously found must be set off inwardly to obtain the corrected points in the curve.

(4.) *To lay out the curve where the use of the chain is impracticable.*

See fig. p. 168, Baker's "Land and Engineering Surveying."

Let A c'' B be a railway curve (obstructions caused by water, marshes, &c. being supposed to exist, such as to prevent the use of the chain), F A D, D B E tangents to the curve at A and B, the portions A D, D B of the tangents being made equal, conformably to the nature of tangents. This equality may be obtained by construction on a large scale, if the accuracy of the survey, which is previously made in these cases, can be depended on; but if the survey be defective, let the point B be moved backward or forward till the angle A B D be found equal to the angle B A D; then A D will be equal to D B. Let c'' be the middle of

the arc A B, p, p^2, p^3, &c., any other equidistant points in the arc, and let A p, p B, A p^2, p^2 B, A p^3, p^3 B, &c., be joined; then it is well known that $\angle p^3$ A B $= \angle$ D A C $=$ $\angle$ A B C, and that $\angle$ A p B $= \angle$ A p^2 B $= \angle$ A p^3 B $=$ &c; $\therefore$ p^3 A B $+ \angle p^3$ B A $= \angle p$ A B $+ \angle$ A B $p =$ &c. $=$ twice $\angle p^3$ A B $=$ D A B; hence this construction.

"Suppose the angle D A B be found to contain 40°, then the sum of the angles C′ A B, A B C′ is 40°; therefore, if the angle C′ A B be taken $= 1°$, the angle A B C′ must be taken $= 40° - 1° = 39°$. These angles may be set out by having theodolites fixed at A and B at the same time, and the corresponding directions A C′ B C′ being fixed upon at the same instant by means of signals, may be continued by means of the poles p p, &c., till they intersect in C′, which will be the first point in the curve. Secondly, take the angle C′ A B $= 2°$, then the angle A B C″ must be taken $=$ $40° - 2° = 38°$, and the lines A C″ B C″ continued, as before, till they intersect in C″, which will be a second point in the curve. In the same manner a succession of points may be found, by continually increasing the angle at A by 1°, and diminishing that at B by the same quantity, till the former becomes 39° and the latter 1°, thus giving thirty-nine points in the curve. It may here be necessary to remark, that the obstructions are sometimes so great that some of the successive points in the curve cannot be found: in a case of this kind it will be necessary to defer the finding of such points till the work of the Railway be so far advanced as to present a better opportunity."—*Gentleman's Diary for* 1838.

Construction, when the Ac, cc′, &c., are each a given distance, d.—Join the points A p p^2, &c., and let A O $=$ radius of the curve $= 40$ chains, $\angle$ A D B $= 100°$; then its supplement $=$ $\angle A\,O\,B = 80°$ and $\angle$ D A B $= 40° = \angle p$ A B $+ \angle$ A B $p =$.

$\angle p^2 A B + \angle A B p^2 =$&c. Now, if $r = A O$, then $\angle A B p$ $=$arc to sine $\frac{d}{2r}$ to radius$=1$, and, if $d=1$ chain, sine $\angle A B p = \frac{1}{80} = \cdot 0125 =$ sine $0° 43'$; whence $\angle p A B =$ $40° - 0° 43' = 39° 17' = \frac{1}{2} \angle A O B - \angle p B A$; $\angle A B p^3 =$ $2 \angle A B p, \angle p^2 A B = \frac{1}{2} \angle A O B - 2 \angle p^2 A B = 40° - 1° 26'$ $= 38° 34'$; in this manner the successive angles at A and B may be found, by doubling, tripling, &c., the angle p B A for the angles at B, and successively subtracting them from $\frac{1}{2} \angle$ A O B; and these angles being laid out, as in the previous construction, will give the points p, p^2, p^3, &c., each 1 chain apart. If the points be required to be 2 chains apart, then sine $\angle A B p = \frac{d}{2r} = \frac{2}{80} = \frac{1}{40} = \cdot 025$ sine $1° 26'$ nearly; whence the other angles may be readily found.

Demonstration.—Join O p; then $\frac{1}{2} \angle A O p = \angle A B c$, and, because O A$=$O c, sine $\frac{1}{2} \angle A O c =$ sine $\angle A B c =$ $\frac{\text{radius } d}{2 r}$; and, by taking$=r=40$, radius$=1$, and $d=1$ chain, sine $\angle A B c = \frac{1}{80} = \cdot 0125 =$ sine $0° 43'$, &c. Q.E.D.

(5.) *Mr. Rankine's method of setting out the curve.*

This method depends on the formula just given, *i.e.* sine $\angle D B p^3 = \frac{1}{2r}$, d being always$=1$ chain. A theodolite is fixed at B, and the $\angle A B c''$ taken, then the distance B $p^4 = 1$ chain is laid out from B to p^4 in the direction of the axis of the instrument; the $\angle A B c^3$ is next taken$=$ $2 \angle A B p^4$, and the distance $p^3 p^4 = 1$ chain applied between c^4 and the direction of the axis of the instrument, thus

giving the point p^4; and so on to the end of the curve. It will be seen that this method, though elegant in theory, is highly objectionable in practice, since the least error at the commencement of the operation will gradually multiply as the work proceeds, whether the error be in taking the numerous angles, or in laying out the distances, or in both, especially if the ground be rough or uneven; whereas, in the method by two theodolites, just given, an error in taking one angle will not affect the rest of the work, but only the point to which the erroneous angle is taken, the position of which point may afterwards be easily adjusted; therefore Mr. Rankine's method ought not in any case to be recommended.

(6.) *To lay out the curve by means of offsets from its chord or chords, when obstructions occur on the convex side of the curve.*

See fig. p. 170, Baker's "Land and Engineering Surveying."

Let B C be a railway curve, A T the tangent at B, O the centre, $OC = Oq$, the radius, B C the given chord, and p its middle point. Draw the tangent $q_1 t$ to middle point q_1 of the curve, and the offsets $m\,p_2$, $n\,p_3$, &c., one chain apart, and cutting the curve in q_2, q_3, &c. In the right-angled $\triangle\, C p_1 O$, C O and $Cp = \frac{1}{2}$ B C are given, whence $O p_1$ may be found, and $O q_1 \;(= O\,C) - O\,p_1 - p_1\,q_1 = C\,t$. Next find the offsets $m\,q_2$, $n\,q_3$, &c., on the tangent $q_1 t$, corresponding to the radius O C by (2), and subtract them successively from $p_1\,q_1$, and the remainders will be the successive offsets, $p_2\,q_2$, $p_3\,q_3$, &c., which may be set off, one chain apart, from p_1 to C, and afterwards, in an inverted order from p_1 to B. The chord B C should always *be taken so* that the offsets may never greatly exceed

2 chains, and if the curve cannot be completed by one chord, B C, other chords, as C D, &c., may be introduced. The tangent $q_1 t$ is not used in constructing the curve, being only introduced to show how the offsets $q_2 p_2$, $q_3 p_3$, &c., are found.

Note.—This method may be advantageously used where obstructions, such as cliffs, water, &c., are close to the convex side of the curve; otherwise it ought not to be used, on account of the tedious calculations involved.

(7.) *To set out the compound curve.*

The compound curve has been defined at the beginning of this article. Let A T, B T, be the prolongations of the straight portions of a line of railway, the point A being required to be joined by a compound curve A B, which is to pass through the point C, and to join the tangent T B, at or near B. Find the radius O A = O C of the portion A C of the curve, and set it out by one or other of the methods already given; then find the position of the common tangent in C n, meeting T B in n; make n B = n C; find the radius P C = P B, and set out the remainder C B of the curve by the method given at (2). The radii of the portions A C, C B may be increased or diminished, as in figures 1 and 2. Moreover, it will at once be seen that three or more curves of different radii may be used to constitute the compound curve, which portions, except the last C B, may be set out in the same manner as A C, by finding the tangents at the several points of junction.

(8.) *To determine one of the two radii of the compound curve by calculation, the other radius and the distance of the tangent points being given.*

Join A B, which put = d; also put A O = O C = R,

$PC = PB = r$, $\angle TAB = \alpha$, and $\angle ATB = \beta$. Then, by the nature of the figure we readily find

$$r = \frac{\frac{1}{2} d\,(2\,R \text{ sine } \alpha - d)}{2\,R \text{ sine}^2 \frac{\alpha + \beta}{2} - d \text{ sine } \beta}$$

By this formula we may readily ascertain whether the radius $r = PC = PB$ be of sufficient length. If it be thought too short, the tangent point B can be moved further towards T, or the radius A O may be diminished, according to the requirements of the case.

(9.) *To lay out the serpentine curve.*

See fig. p. 172, Baker's "Land and Engineering Surveying."

The serpentine curve has its convexities turned different ways, as in the figure. Let A B T, T′ D be the straight portions of a line of railway, the point B being required to be joined by a serpentine curve A P R Q C, which is to pass through R, and to join T′ D tangentially at or near C. Find the radius B O=O R, and set it out by one or other of the methods already given; then find the position of the common tangent T R T′, meeting T D in T′; make T′ C=T′ R; find the radius R O′=O′ C, and set out the remainder R C of the curve. It will be at once seen that three or more curves, of the same or different radii, may be used to constitute the serpentine curve, which portions, except the last R C, may be set out in the same manner as B P R, by finding the tangents at the several points of junction.

(10.) *To find the radius* R O′=C O′ *of the serpentine curve by calculation, when the distance* T T′ *and the radius* B O=O R *are given.*

Put $\delta = T\,T'$, $R = O\,B$, $r = O'\,C$, $\mu = \frac{1}{2} \angle B\,T\,T'$, and

$\nu = \frac{1}{2} \angle$ C T′ T; then R cot μ = T R, r cot ν = T′ R, and T T′ $= \delta =$ R cot $\mu + r$ cot ν, whence $r = \frac{\delta - R \cot \mu}{\cot \nu}$, which determines C O.

Corollary.—When $R = r$, then $\delta = r$ (cot μ + cot ν), or $r = \frac{\delta}{\cot \mu + \cot \nu}$, whence the common radius B O = C O′ becomes known, and the curve may be set out as before.

(11.) *To lay out the serpentine curve, when the distance* B C *and the radius* B O *are given, as in* (8).

Put d = B C, R = B O, ν = C O′, $a = \angle$ T B C, and $\beta = \angle$ T′ C B; then, by the nature of the figure we readily find $r = \frac{\frac{1}{2}d\,(d - 2 R \text{ sine } a)}{d \text{ sine } \beta + 2 R \text{ sine}^2 \frac{\beta - a}{2}}$. By this formula we may readily find whether the radius r = O′ C is of sufficient length as in (8).

(12.) *To make a given deviation* (B P Q R C) *from a straight line of railway* (A H D), *that the works of the line may avoid a building* (h), *or any other obstruction, situated on or near the line.*

See fig. p. 174, Baker's "Land and Engineering Surveying."

Take H Q for the required deviation, and O Q = O′ C = O″ B for the common radius of the deviation curves P R, R C, P B; put this radius $= r$, and H Q $= d$; then from the nature of the figure, we readily find H B = H C = $\sqrt{d\,(4\,r - d)}$, and the four equal chords, B P, P Q, &c., are each $= \sqrt{d\,r}$, also B Q = Q C $= 2\sqrt{d\,r}$; whence the deviation curves may be readily laid down by one or other

of the methods already given, since the triangle B Q C is now known, and the points of contrary flexure, P and Q, are the middle points of B Q, Q C, through which the common normals O O′, O O″ pass, the position of which, however, need not be found.

Note.—All the formulæ, used in laying out railway curves, as well as those hereafter used for setting out cuttings and embankments, are given with the several steps of their investigations, in Baker's "Railway Engineering," and in his "Land and Engineering Surveying:" the details of which, it is presumed, would unnecessarily increase the bulk of a work of this kind.

DIVISION V.

ON SETTING OUT THE SURFACE-WIDTHS OF THE CUTTINGS AND EMBANKMENTS OF RAILWAYS.

THE simplest case of setting out surface widths is when the ground is level, and also coincident with the formation level of the intended railway. Let A B be the formation level, and also the surface of the ground; *m* the centre stump of the line; then half the width of formation level being set out perpendicularly to the direction of the line from *m* to A and B; and to each half width the intended widths of A A′, B B′ of the side fences must be added; when stumps may be put down to mark the half widths and breadths of the fences.

(13.) *To set out the width of a cutting when the surface of the ground is level, and at a given height above the formation-level, the ratio of the slopes being given.*

Here A B is the formation-level, C′ D′ the horizontal surface of the ground, A C′ B D′ the side slopes, M the centre stump, and M $m = b$ B the depth of the cutting. Let $w =$ A B, $d =$ M $m =$ B b, and $r =$ ratio of the slopes; then $1 : r :: d\ (=\text{B}\,b) : d\,r = b\,\text{D}'$; $\because$ M D′ = M C′ $= d\,r + \frac{1}{2}\,w$; and $2\,(d\,r + \frac{1}{2}\,w) = 2\,d\,r + w =$ C′ D′ = surface width

of cutting; to which the breadths R′ C′, S′ D′ of the side fences must be added.

Note.—If the cross-section A C′D′ B be inverted, it will evidently show the cross-section of an embankment of the same dimensions.

(14.) *The same things being given as in* (13) *to set out the width of the cutting, the ground having a given lateral fall in a given horizontal distance.*

See fig. p. 184, Baker's "Land and Engineering Surveying."

Let A B D C be a cross-section of a cutting, C D the sloping surface of the ground, and R′ S′ a level line passing through the centre stump M, M D′ being the computed half width, as found by (13). Place the level so that by turning the telescope, 3, 4, or more chains of the line may be clearly seen, on both sides of it; fix a levelling staff at M, and another at n, at a convenient distance from M, and mark the level readings on both staves, the difference of which is $= m\,n$; then measure M m, M n with a tape-line in feet. Put $m\,n = h$, M $n = t$, and M $m = s$, the computed half width M D′ = M C′ = w', and the ratio of the slopes $r : 1$, as in (13). Then by the nature of the figure we readily find

$$\text{M C} = \frac{w'\,t}{s + r\,h}, \text{ and M D} = \frac{w'\,t}{s - r\,h},$$

which are the corrected distances from M.

Note.—If the cross-section A B D C be inverted, it will evidently represent the section of an embankment having the same dimensions; but, in this case, the longer distance must be measured down, and the shorter distance up the slope.

(15.) *To set out the surface width where the ground is uneven.*

See fig. p. 186, Baker's "Land and Engineering Surveying."

The width of the surface, C M D, of the cross-section,

A C D B, being very uneven, is found, by approximation, as follows:—Let A B=32 feet, M m'=26 feet, and the ratio of the slopes as 2 : 1; then M C′=M D′= $26 \times 2 + \frac{1}{2} \times 32 = 68$ feet, by (14); set off this distance horizontally from M to p, then p is directly above D′. Find the difference of level between M and p, which in this case is 8 feet, which being multiplied by the ratio of the slopes, *i.e.* by 2, gives 16 feet=approximate distance p D; $\therefore$ M D=M p+p D=68+16=84 feet. Again, find difference of level between M and D, which in this case is 9·2, or 9·2−8=1·2 feet greater than at p; $\therefore$ the position of D requires further correction, which is thus done: $1{\cdot}2 \times 2 = 2{\cdot}4$ feet, whence M D=84+2·4=86·4 feet. Now, as the latter correction is small, the true distance M D may be assumed to be found, which corresponds to the horizontal distance M q. But if this be thought not sufficiently correct, another approximation may be repeated in the same manner. The method of obtaining the other corrected distance, M C=M m, is performed in the same way as the one just given, excepting that the repeated corrections are subtracted from M C′, instead of being added to it. When the difference of levels at M and D is very great, it will require four, five, or more approximations, similar to those shown above, to obtain the corrected half widths; also this section may be inverted for an embankment, as in (14).

(16.) *To set out the surface width when the cross-section consists partly of a cutting and partly of an embankment.*

See fig. p. 185, Baker's "Land and Engineering Surveying."

Here A B is the formation-level, M m the depth of the

cutting, the cross-section consisting of the cutting P B D, and the embankment P A C. Having obtained the difference of level corresponding to given distances on the sloping surface M C, and on the level M D′; which, with A B and M m, may be represented by the same symbols, as in (13). When the cutting extends over more than ½ A B, M D is found by the formula given in (13); and M C= $\frac{(2\,w-w')\,t}{s-r\,h}$, wherein w=A m=m B. When the sloping surface C D passes through m, *i.e.*, when M, m, and P coincide; then $w'=w$, and M C=M D=$\frac{w\,t}{s-r\,h}$. In this case the cutting and embankment are equal.

Note.—It will at once be seen that, by inverting the figure, a like calculation will be required, when A P C is a cutting, and B P D an embankment.

DIVISION VI.

RAILWAY TUNNELLING.

(17.) WHEN the depth of the excavations of a railway becomes 60 feet or upwards, the ground afterwards rising rapidly for a considerable distance, the further progress of the works will be effected in the most economical manner by tunnelling. Previous to laying out the earthwork of a tunnel, the levelling operation must be repeated with great care, and properly checked as to its accuracy, especially when the tunnel passes under a very high summit: for, if the section be inaccurate, the gradient or gradients on which the tunnel is formed will be found in practice not to meet at the points shown on the section, and thus greatly embarrass the mining operation. If only one gradient is used in the formation of the tunnel, it must incline to one of its extremities to discharge the water generated therein. Strong poles must be firmly fixed on the surface of the ground, in the proposed direction of the tunnel. Shafts must be sunk at the distance of 5 or 6 chains from one another, in the line of the poles, to ventilate the tunnel, and check the accuracy of the work as it proceeds, the depth of the shafts being determined by measurement from the section. If the tunnel be a long one, and in wet ground,

it would be preferable to form it on two gradients, inclining to its two ends to liberate the water, which would greatly aid the mining operation, which is usually commenced at both ends of the tunnel at the same time. Moreover, a head-way, 5 feet in height and 3 in width, may be readily formed for the liberation of the water in the tunnel and the shafts; the more extensive works of the tunnel may, in this case, be also commenced at the bottom of the shafts, as soon as they are sunk. When a curve is required in the direction of a part or the whole of a tunnel, the curve must be carefully laid down on the surface, by one or other of the methods given for laying out railway curves, making proper allowance for acclivities and declivities, fixing poles in the direction of the curve, that the shafts may be sunk to meet the mining work of the tunnel, and check their accuracy, which is more especially necessary when the tunnel is curved.

The width and depth of a tunnel, on the narrow gauge, should be about 30 feet each, and must extend 5 or 6 feet below the intended line of the rails; thus giving space for the inverted arch and the ballasting; but where the excavation is made through rock sufficiently hard to form the bottom and side walls of the tunnel, 22 or 24 feet in width, and about 26 in height, will be sufficient, the excavation being in this case terminated upon the formation-level. For a tunnel on the broad gauge, the depth and width must, in both cases, be proportionably larger.

The figure, p. 191, Baker's "Land and Engineering Surveying," shows the cross-section of the masonry of a tunnel, being such as is required where the tunnel is cut through loose earth; *a b* is the level of the rails, and *m n* the formation-level; only the arch A B is required when it *is made* through hard rock, the interior of the side walls

A a, B b, and the formation level $m\ n$, forming the boundary of the excavation.

Centrifugal force of trains in railway curves.

Since all moving bodies have a tendency to preserve their motion in a direct line, hence a railway train of great velocity, when moving in a curve, is strongly impelled towards the exterior rail, and would readily leave the rails were it not prevented by the flanges of the wheels and the conical inclination of their tire. Let F = centrifugal force thus generated, R = radius of the curve, W = weight of the train, V = its velocity, and g = force of gravity at the earth's surface; then by Dynamics: $F=\frac{W\ V^2}{g\ R}$. From this formula, when $R=\frac{1}{2}$ a mile $=2640$ feet, V = velocity = 60 miles per hour = 88 feet per second, and $g=32$ feet; then $F=\frac{W\times 88^2}{32\times 2640}=$ nearly $\frac{1}{11}$ W; that is, the force is $\frac{1}{11}$ of the weight of the train, at once showing the extreme danger of high velocities in curves of small radius. Except in curves of very small radius, this force is counteracted by the conical inclination of the tire of the wheels of the train, which increases the diameter of the outer wheels, and diminishes that of the inner ones, and which causes the train to roll on a conical surface, thus necessarily generating a centripetal force to counteract the centrifugal force. However, in curves of very small radius, these forces are not sufficiently counteracted by the form of the tire, and a proper superelevation of the exterior rail is required for the purpose; for determining which Pambour has given the following—

Formula for the superelevation of the exterior rail.

Let R=radius of the curve, R′=radius of the curve which the train would describe in consequence of the centrifugal force and the inclination of the tire of the wheels, e=gauge of rails, g=force of gravity, V=velocity, and x=superelevation of the exterior rail; then $x=\frac{eV^2}{g}\left(\frac{1}{R}-\frac{1}{R'}\right)$, in which $R'=\frac{den}{4\,\Delta}$, wherein d = outer diameter of wheels, Δ = their deviation, and $\frac{1}{n}$ = inclination of the tire. The correctness of the results derivable from these formulæ are pretty generally conceded.

OFFSETS AT THE END OF THE FIRST CHAIN FROM TANGENT POINT OF RAILWAY-CURVES.

Radius of curve in chns.	Offsets in inches & decimals.	Radius of curve in chns.	Offsets in inches & decimals.	Radius of curve in chns.	Offsets in inches & decimals.	Radius of curve in chns.	Offsets in inches & decimals.
40	9·9000	64	6·1875	88	4·5000	120	3·3000
41	9·6588	65	4·0923	89	4·4496	125	3·1680
42	9·4285	66	6·0000	90	4·4000	130	3·0461
43	9·2093	67	5·9104	91	4·3516	135	2·9333
44	9·0000	68	5·8235	92	4·3043	140	2·8285
45	8·8000	69	5·7391	93	4·2581	145	2·7310
46	8·6087	70	5·6571	94	4·2128	150	2·6400
47	8·4255	71	5·5774	95	4·1684	155	2·5548
48	8·2500	72	5·5000	96	4·1250	160	2·4750
49	8·0816	73	5·4246	97	4·0825	165	2·4000
50	7·9200	74	5·3513	98	4·0408	170	2·3294
51	7·7647	75	5·2800	99	4·0000	175	2·2628
52	7·6154	76	5·2105	100	3·9600	180	2·2000
53	7·4717	77	5·1428	102	3·8824	185	2·1405
54	7·3333	78	5·0769	104	3·8077	190	2·0842
55	7·2000	79	5·0126	105	3·7714	195	2·0307
56	7·0714	80	4·9500	106	3·7358	200	1·9800
57	6·9473	81	4·8889	108	3·6667	205	1·9397
58	6·8276	82	4·8292	110	3·6000	210	1·8857
59	6·7118	83	4·7711	112	3·5352	215	1·8418
60	6·6000	84	4·7143	114	3·4736	220	1·8000
61	6·4918	85	4·6588	115	3·4435	225	1·7600
62	6·3871	86	4·6046	116	3·4138	230	1·7217
63	6·2857	87	4·5517	118	3·3559	235	1·6851

The methods of laying out railway curves, tunnels, cuttings, &c., here given, were first designed, and the necessary formulæ investigated by *T. Baker, C. E.*, at the commencement of the railway era; and have since that time been fully adopted in practice, not only in this kingdom and its colonies, but also in foreign countries, having been repeatedly published in his *Railway Engineering*, and in his other practical works.

DIVISION VII.

MECHANICAL DETAILS AND ILLUSTRATIONS.

THE practical operations of ranging, staking, and nicking out the centre line; of setting out and testing the curves, and of adapting them to the various circumstances and obstructions which continually arise; the fixing the level pegs and permanent posts, taking the cross sections, plotting the working sections to scales (usually of 3 chains horizontal, and 50 feet vertical, to an inch), ascertaining quantities, the setting out the slopes and widths, the foundations and work generally, as well as full particulars of the tools and instruments employed, are treated at length in the various publications devoted to the more detailed illustration of the subject.

Boring, with a description of the most useful tools, forms the subject of a separate work.*

The Fencing may be of brick wall; of rubble, with dressed coping; of posts, rails, fences, and ditches; or of growing and impervious hedges;—the ditches proportioned to the quantities of water to be carried off, and discharged into the nearest water-course;—the gradients, curves, and slopes of each work, determined according to local circumstances and the materials employed.

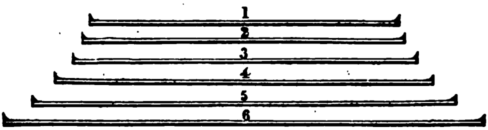
The average proportions of Materials required for a

* Vol. 31, Rudimentary Series.

Trunk Line, of double way, per mile, may be estimated at:—Earth works, 100,000 cubic yards. Ballasting, 30 feet wide, 24 inches thick, 11,740 cubic yards. Sleepers, 3,520, 5 cubic feet each, 350 loads. Chairs, joints, 42lbs., 1,410, 26 tons. Chairs, intermediate, 28lbs., 5,640, 70 tons. Rails, 84lbs. per yard, 264 tons. Wedges, compressed elm, 7,050. Bolts, or compressed treenails, 14,100. Fencing, if not of quick or shrubs, 120 loads. Masonry—Bridges, 2¼ per mile. Culverts, 176 per mile. Stations, one every 5 miles.

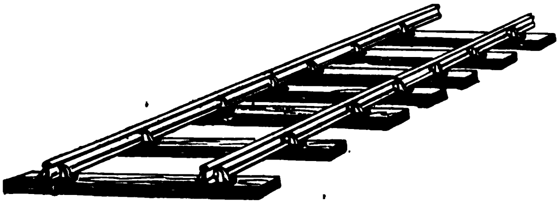
The relative proportions of charges for cost of Railway works have been roughly estimated as land, 10 per cent.; stations and carrying establishment, 20 per cent.; management, 10 per cent.; iron, 10 per cent.; works of construction, 50 per cent.; and the total expenditure at 3*s.* per mile, per train; of which the locomotive charges were 1*s.* 6*d.*; depreciation and interest, 6*d.*; carriage charges, 4*d.*; duty, salaries, management, establishment and maintenance, 8*d.*

The essential points of difference in the principles of construction may be defined as a varying gauge, ranging from 4 feet 8½ inches to 7 feet, as under:—

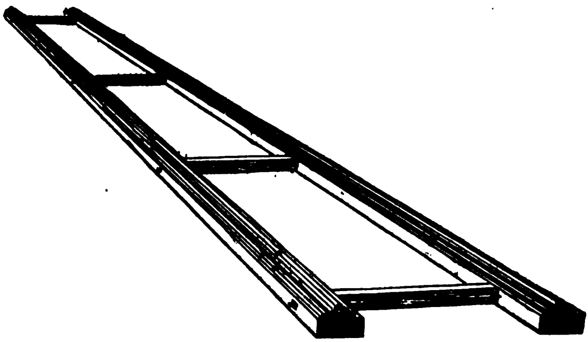


No 1.—4 feet 6 inches, originally laid down in Scotland. No. 2.—4 feet 8½ inches, the gauge in most general use. No. 3.—of 5 feet, formerly adopted for the Eastern Counties and Blackwall lines. No. 4—of 5 feet 6 inches, used in Scotland. No. 5.—The Irish gauge of 6 feet 2 inches; and No. 6, the Great Western of 7 feet gauge.

And the adoption of transverse sleepers and intermittent supports, at unequal intervals, with edge rails, or continuous longitudinal bearings, with a bridge rail, as shown on the annexed sketches.

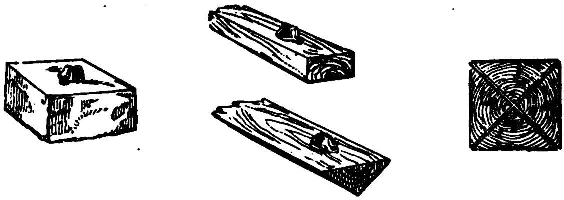


Edge Rail, with transverse sleepers.



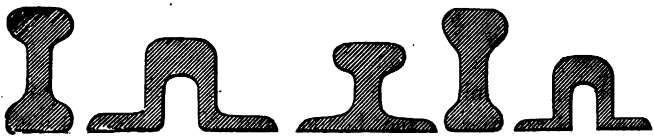
Bridge Rail, with longitudinal bearings.

The forms of rails, chairs, modes of fastening, section of sleepers, combined chairs and sleepers, of cast and wrought iron, the use of hollow iron or compressed wood wedges, the turn table, switch, water crane, and other parts of the work, admit of great variety and modification, and have each their advocates and claims to superior advantages. They are rather deviations of detail than questions of principle. The annexed diagrams illustrate several of the plans *in operation.*



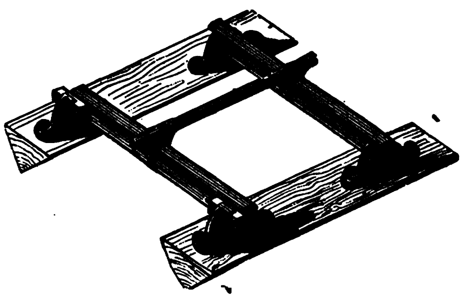
The sleepers, as shown above, are of stone, in blocks of about 4 cubic feet, or of timber, squared, or cut diagonally with a triangular section, or half-round, as in the case of larch and other descriptions of trees, of which the trunk is cut in lengths of 9 and 10 feet and divided.

Of rails, the following are the most approved sections.

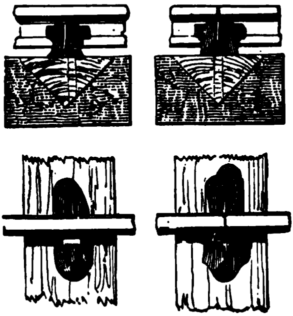


The first and fourth are the 72lb. and 84lb. rails of the London and North Western Company. The second and fifth, the best forms of bridge rail, and the third shows the most approved section of foot rail in use.

The form of cast-iron chair in most general use, with the compressed wooden wedge and trenails, and the adjusting gauge, are shown in the annexed sketches.

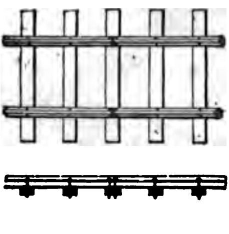


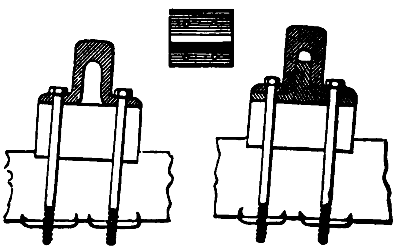
The following cuts show the mode of fixing and the proportions of the joint and intermediate chairs, with the instruments used for boring the trenail holes with accuracy and despatch.



Upon this subject, the report of Mr. Dockray, respecting the relaying of the London and North Western line, deserves especial consideration.

The substance of this really valuable document is the strong recommendation to adopt, in the renewal of the permanent way, a principle, which will be understood by reference to the annexed sketches, as in Mr. Dockray's opinion combining the advantages and avoiding the defects which in greater or less degree attach to the works upon all the other lines he had examined.



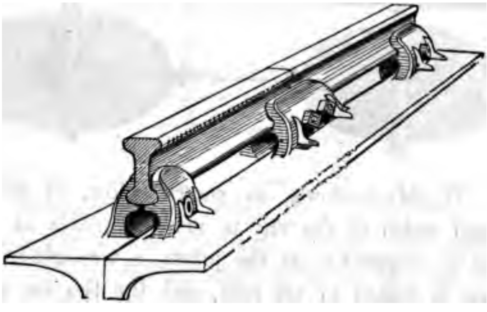


The plan and elevation show the general arrangement. The three enlarged sketches show the bridge rail, bolted at the joints and on the intermediate cross sleepers, with the wrought-iron shoe used where the rails meet. The longitudinal bearing, the secure mode of fastening, and the means by which the uniform inclination or cant of the rails is obtained, are clearly indicated.

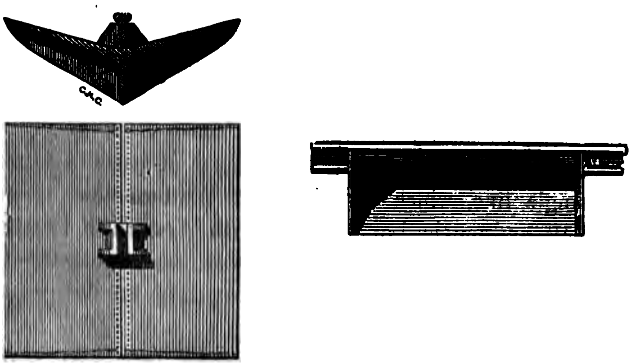
Under this arrangement, the number of parts in a mile of single line, which on the Great Western amounts to 28,512, and on the London and North Western to 17,248, will be reduced to 13,376, the cost being respectively 6*l.* 15*s.*, 6*l.* 5*s.*, and 7*l.* 5*s.* per length of 15 feet, when the price of rails was 10*l.* per ton.

Among the numerous inventions which have been tried for the improvement and for the greater economy of construction and maintenance of the permanent way, a few may be mentioned as possessing a sufficient degree of novelty in principle and practical character to justify their enumeration. See division 10.

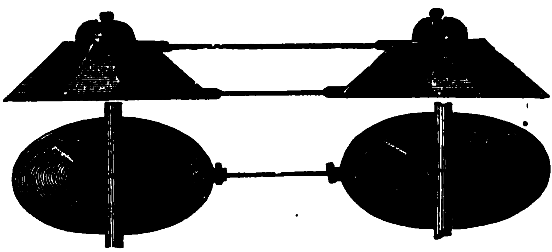
The cast-iron combined sleeper and chair of Mr. Barlow, which has been laid down on the South Eastern line, will be understood from the following sketch:—



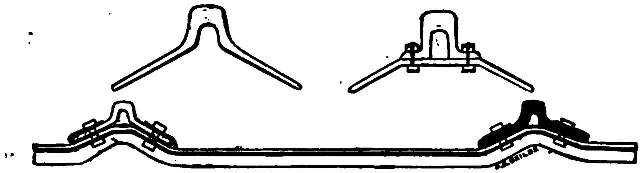
Mr. W. Brunton's combined cast-iron chair and sleeper is shown in the annexed sketch :—



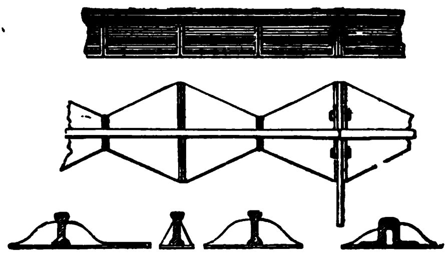
Mr. Greave's combined cast-iron hollow sleeper or block and chair, in a single casting, the rails being keyed up in the usual manner, and the gauge of rail preserved by ties to each set of sleepers, as shown in the annexed sketch :—



Mr. W. H. Barlow's, as shown below, in which the increased width of the rail is made available as a bearing for its support ;—at the joints, a wrought-iron plate or shoe is bolted to the rails, and the ties are of broad wrought iron.



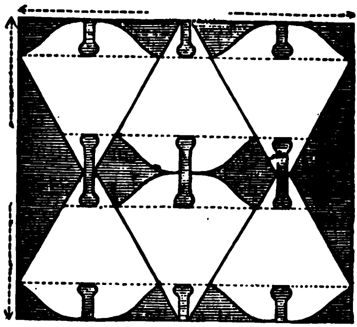
Another mode of construction is that of Sir Macdonald Stephenson's to provide against the contingency of its being found impossible to preserve and protect the wood sleepers in tropical climates. The diagram shows the arrangement by which a continuous bearing is obtained with any form of rail, and without the use of wood at all. No wedges or bolts are required, except at the joints, and no cast iron is made use of. The principle consists in the previous preparation, by shaping, punching, and bending wrought-iron boiler plate, of about $\frac{1}{2}$ or $\frac{5}{8}$ thickness. The ends are turned up and abut one against the other, the rail being inserted into the opening punched out of the plates to receive it, and forming a clip which effectually secures the rail under all circumstances.



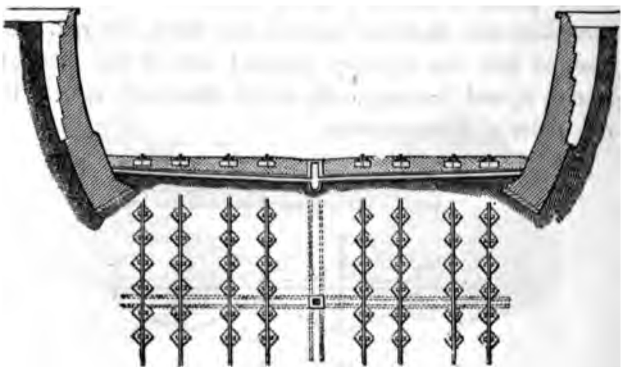
At the joints is inserted a cheek of 1 inch plate, similarly punched to receive the rail, and bolted to the ends of the bent plates. The cheek is tapered to form the connecting rod between the two rails.

The annexed rough sketch will show the mode of pr

paring the plates, the dark part being cut away, and the ends bent up at right angles.

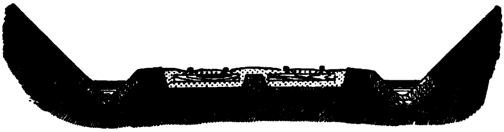


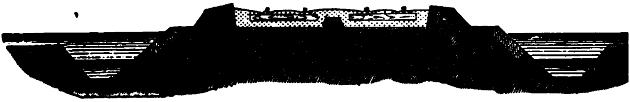
The several forms of construction and station apparatus are shown in the following sketches.



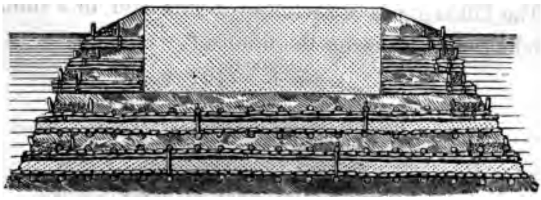
The above section and plan show a line in cutting, with retaining walls, the longitudinal and cross drains, and stone blocks, which have given place very generally to wood sleepers, the elasticity of which, as compared with the rigidity of the stone, tends to materially diminish the *ᵉ*
of maintenance of way, and current repairs.

The two following sections represent a cutting and embankment, with provisions for drainage, and the preservation of the banks by pitching. Wood sleepers are shown in both sections, and on the latter, the line is assumed to be laid in a district subject to inundation, and to be occasionally under water.





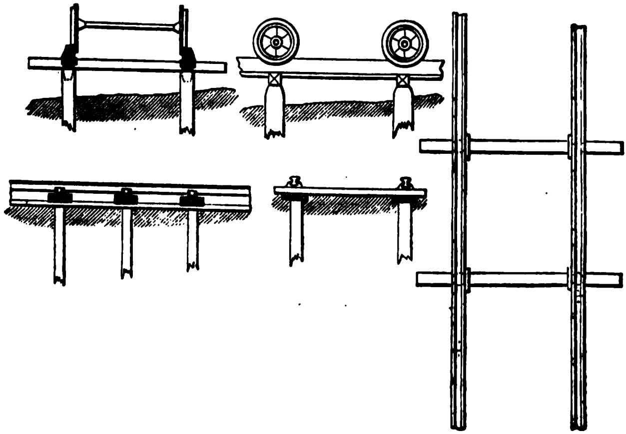
The annexed section is taken from one of the lines Holland, which passes through wet and marshy land, and is formed of fascines and stakes bound together, and laid alternately across and longitudinally.



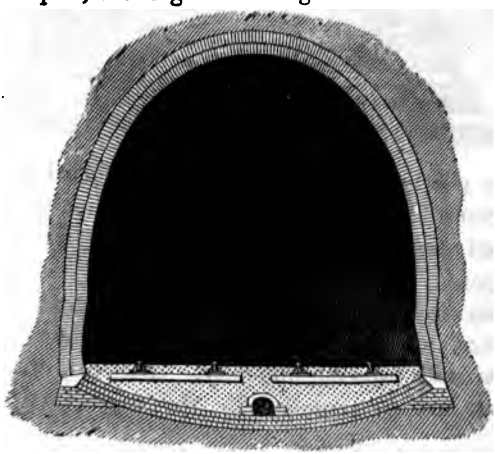
The pile lines which have been constructed in parts of the South American States, where circumstances have induced their adoption, are shown in the following sketches.

They are only applicable where the loads are light, timber abundant, and where the usual mode of construction is attended with especial difficulty. The objection to their *subsidence* will be removed by the use of the screw p

elsewhere referred to. They are composed of a series of piles, securely connected by cross timbers, and a longitudinal framing, on which a plain bar of iron, or a light rail and chair are laid. When the piles rise much above the ground level, diagonal braces require to be introduced.



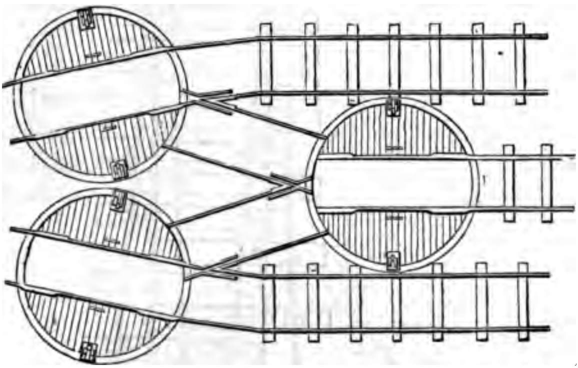
The following is a sketch of a line laid in a tunnel on wood sleepers, showing the drainage.



The operation of diverting, by means of turn tables, an engine, carriage, or waggon from one to another line of rails, will be readily understood by reference to the following sketch.

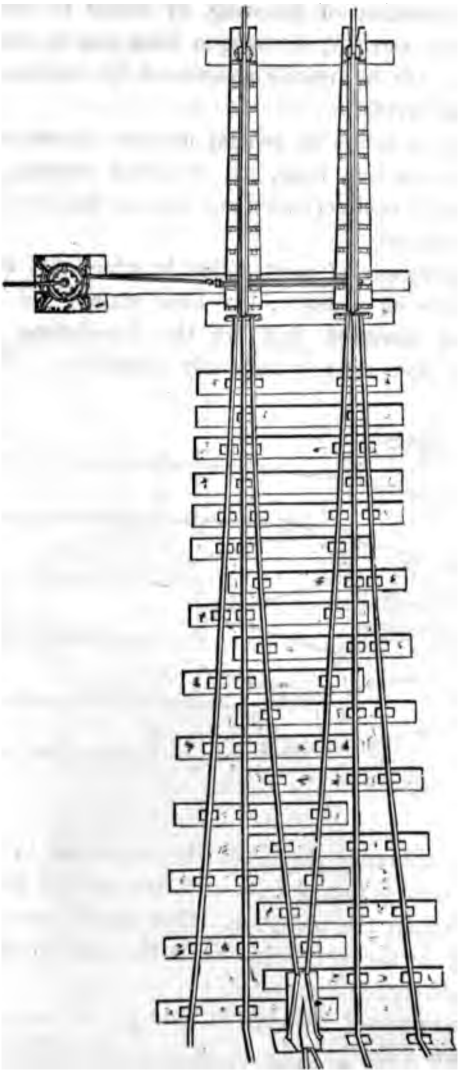
The turn tables in general use are of cast iron, with wrought-iron ties, bolts, and revolving gearing; they are occasionally made of wood and iron, as well as of wrought iron exclusively.

The principle of construction by which they were made to revolve on a centre, has been entirely set aside, as entailing increased cost for the foundations, and the original plans are now uniformly adhered to.

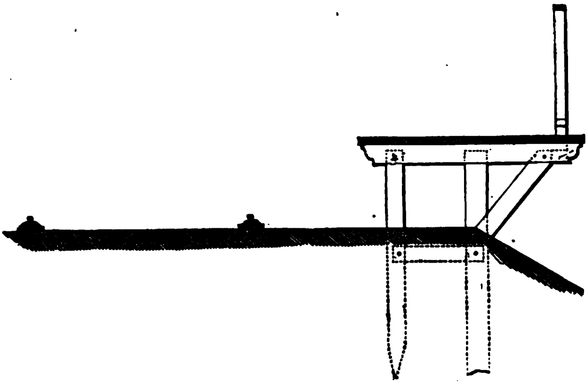


The following sketch of the apparatus by which an entire train is turned from one into another line of rails, will explain the operation. The single line of rails is shifted by the switch (shown at the side) to either of the *three diverging* lines.

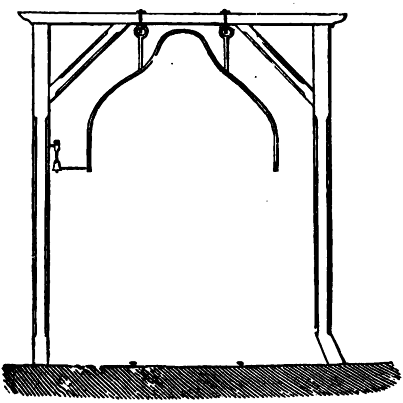
The improved switches in most general use are those *Wild and Fox.*



The following sketch shows the position in relation to the line of rails of the ticket platform, to or near the entrance of a station.

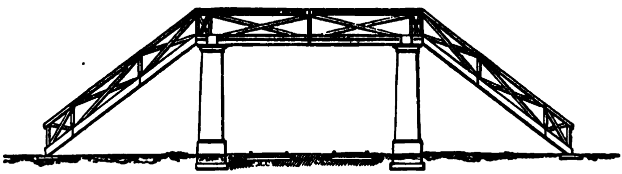


The simplicity of the means employed to prevent the loading of waggons exceeding the limits allowed for passing through tunnels and under bridges, will be understood by the annexed sketch of a frame, with a bell

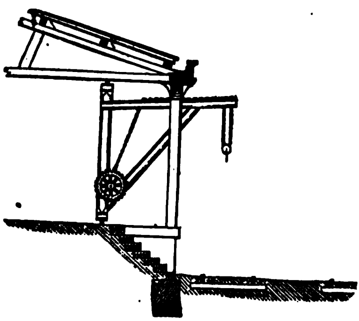


attached to it, under which the loaded waggons readily pass, so long as their loading does not exceed the prescribed limits.

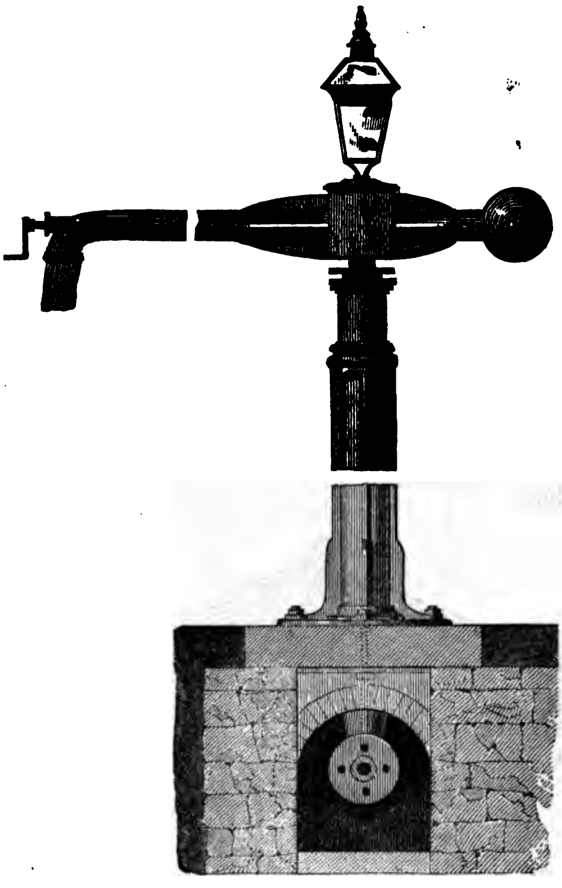
The following sketch shows the mode of keeping open the communication for foot passengers between the two sides of a line of Railway, without crossing on the level.



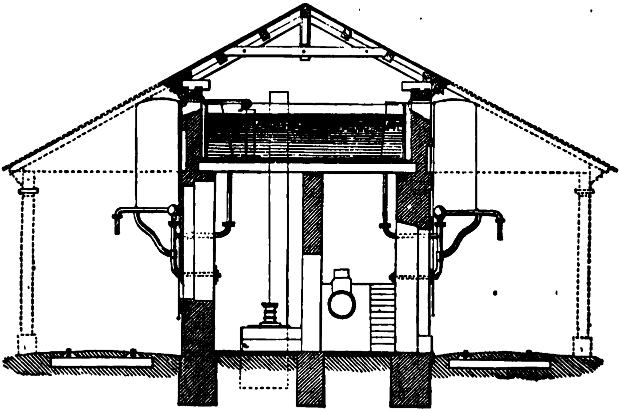
The following is a sketch of the goods' crane, showing its position in relation to the Railway, and the facilities afforded for loading and discharging the waggons.



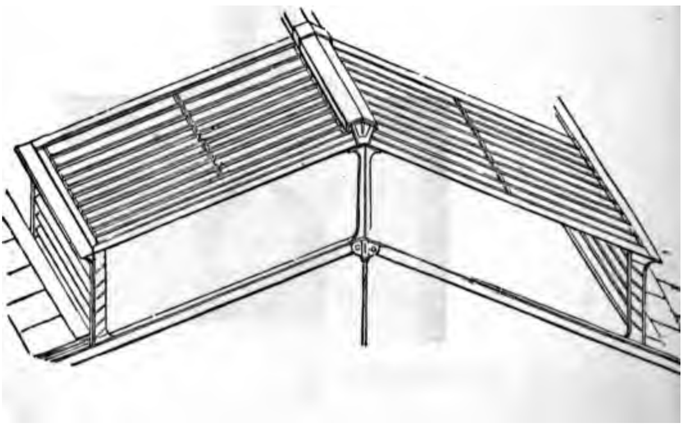
he annexed sketch shows, on an enlarged scale, a ;ription of water crane in very general use, but which either so simple nor economical a form as is shown in smaller diagram in which the water is contained in a ;rn above the crane.

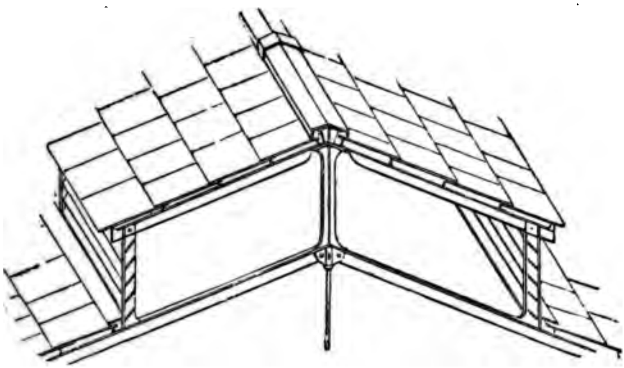


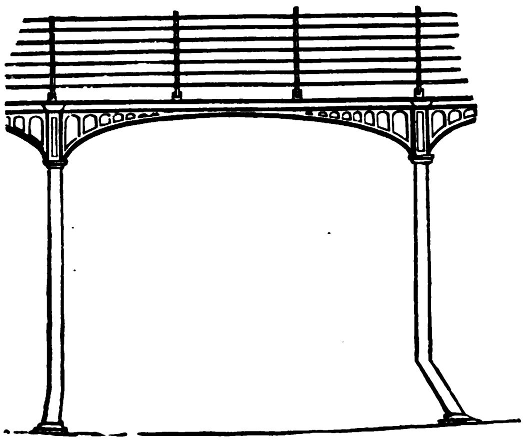
In the annexed sketch, the water cistern is placed above the cranes, two of which are supplied from the same source.

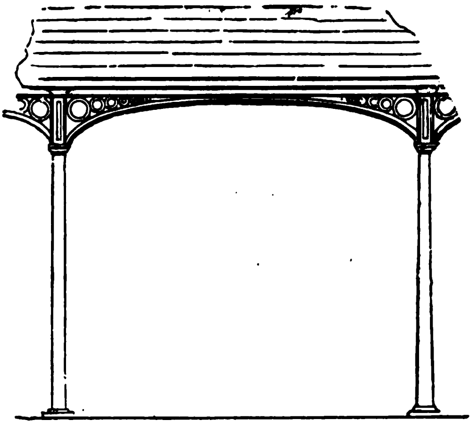


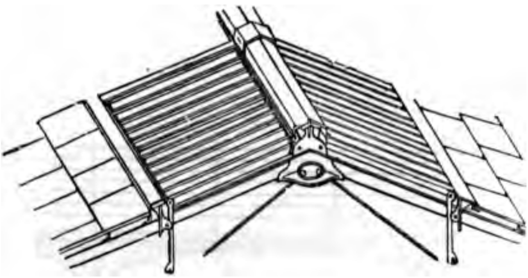
The following are enlarged scale sketches of roofs of various descriptions, erected by the late firm of Messrs. Fox, Henderson & Co., and the general appearance will be seen by reference to the perspective sketch which follows.

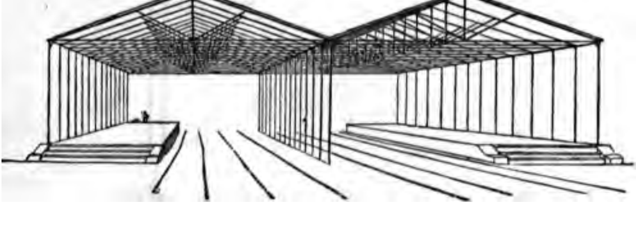




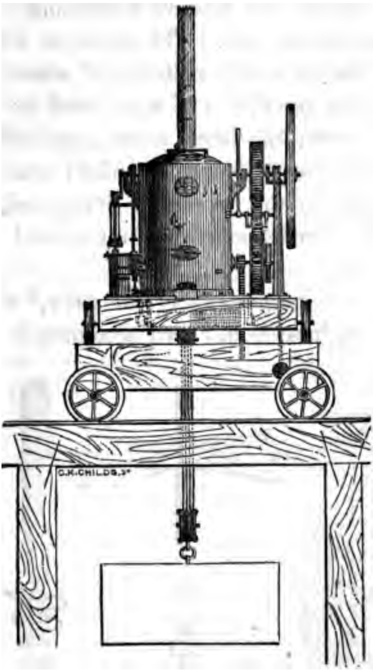








One of the most valuable auxiliaries of a Railway contractor, is the portable engine, of which there are two forms in most general use, vertical and horizontal,—the former of which is shown in the annexed sketch. Its application to all the varying purposes of contractor's work, will be readily understood from its lightness, economy, and portability. It is here shown upon a traversing platform raising the materials for a building.

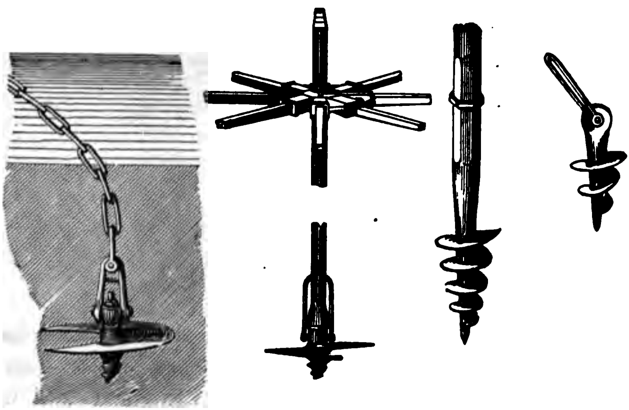


The simplicity and cheapness of what are known as the Volute Springs, entitle them to consideration now *that they have* been in use, both in England and on *the continent,* for a sufficient period to attest their pro

tical utility. The annexed diagrams will explain their construction :—

The screw pile, already referred to, is one of the most simple, economical, and effective contrivances of this pre-eminently mechanical age. The principle will be understood from the following sketches, of which the smaller figure shows the description of screw used for signal, mile, or telegraph posts; the larger screw is applied to the more substantial purposes of foundation piles; and the mooring screw is shown in the process of fixing, and, as it afterwards remains firmly embedded in the sand or silt of a river or harbour.

The form and proportions of the screw,* as well as the mode of fixing, have been varied according to the views of



* Mitchells

different engineers, but the principle is the same, and its practical value is undisputed.

One of the suggestions for Railway carriage wheels, is the use of solid wrought iron for tyres, nave, and the interval usually occupied by the spokes, the entire wheel being rolled, hammered, and shaped out of the solid. The weight is expected to be less than that of the wheels in use, and the price the same. It is referred to only as partially in use, and yet to be regarded as an experiment.

The subjoined analysis of the cost of the several items of expenditure upon the Taunus Railway, which, although of a date of fifteen years, is extracted from Mr. Thorman's interesting account of that work, and will give an insight into the comparative outlay for the construction of, a Continental or Colonial Line (not being a trunk), of moderate average cost.

Taunus Railway.—26 Miles. Francfort to Weisbaden. Gauge 4 ft. 8½ in. Bridges, &c., for double line. Single rails only laid. Rails 58lbs., cost delivered £16 per ton. Sleepers, 12 inch to 16 inch, 3*s.* 4*d.* each. Blocks, 24 × 24 × 12, 4*s.* 2*d.* each. Average, six through trains daily each way.

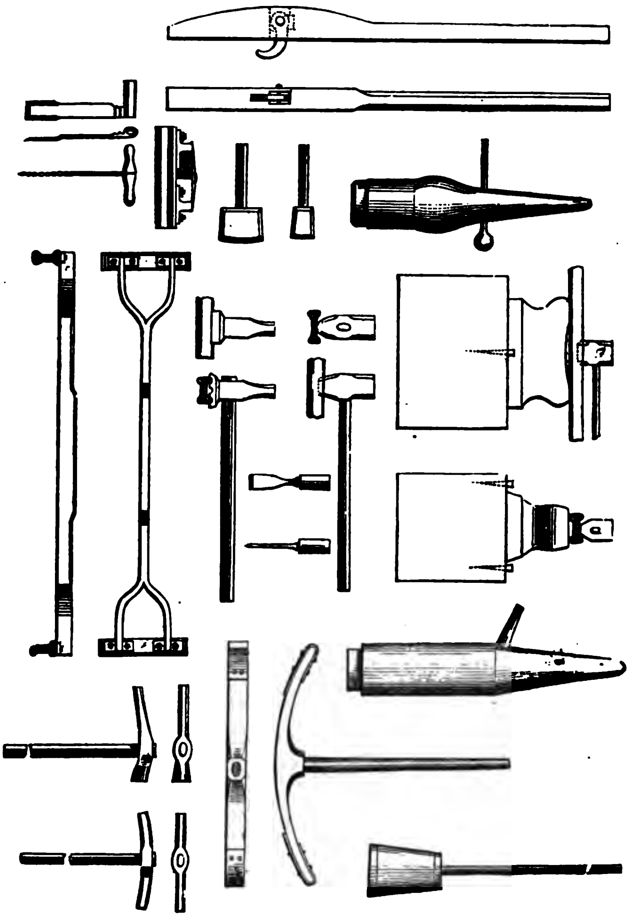
	Cost of Taunus, £ per mile.	Assume for a Colonial Line of 50 to 100 miles of average work.
Surveying, Engineering, &c.	561	600
Earth Works	669	700
Bridges and Culverts	436	500
Walling	67	100
Ballast	214	300
Blocks and Sleepers	650	700
	2597	2900

	Cost of Taunus, £ per mile.	Assume for a Colonial Line of 50 to 100 miles of average work.
Brought forward .	2597	2900
Rails	1897	1900 *
Chairs	449	500
Nails, Keys and Dowells	78	100
Felt for Chairs	8	
Laying Rails, Chairs, &c. . . .	142	200
Twenty-five Switches, Crossings and Points	41	100
Turnpike and Cross Roads	54	100
Fencing, Posts, Warning Tables . .	114	200
Turn Tables, 16 large 13 small . . .	136	200
Stations and Watchhouses . . .	1019	1100
Boundary Stones	4	100
Extra expenses, at	42	
Water Tanks, Cranes, Pumps, &c. . .	25	100
Work not previously included . . .	21	
	6627	7500
Deduct materials not used, &c. . . .	169	1300
	6456	6200
Land (usually granted free of cost) . .	2088	0
Six Locomotives, Tenders, and duplicate parts	559	650
Eighty-seven Carriages, 21 Trucks . .	813	900
Expenses of administration . . .	179	200
Workshops, Tools, &c.	76	100
Electric Telegraph	11	50
	10182	8100

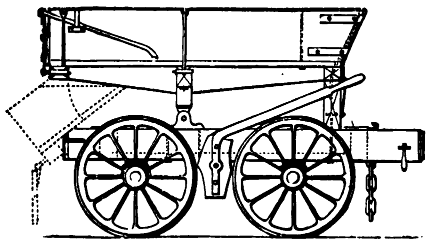
* Will be 2,500 at £16, but at £8, and 84lbs. Bridge rail.

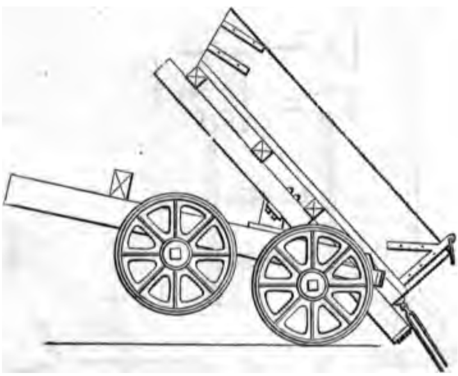
132 tons or	1056	
Spikes, &c.	144	
		1200

The annexed plate will show the description of tools employed in laying the line of Railway.



One of the cheapest and most useful descriptions of contractor's earth waggon is shown in the annexed sketches.





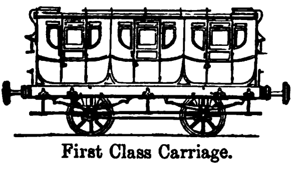
A light description of engine and carriage combined has been recently used on some of the lines, and is well adapted for branches or light traffic. The total cost is £1,800. Accommodating 20 first class and 96 second class passengers, by the use of bow springs, with double movement, it can traverse curves of 5 chains radius, running on 8 wheels, and travels with this load at 30 *miles an hour, with* a consumption of 10 lbs. of coke per *mile. Of the £1,800,* the small engine costs £1,230, the

carriage £570. A smaller description of engine and carriage, to convey 24 first class passengers only, will cost about £1,000.

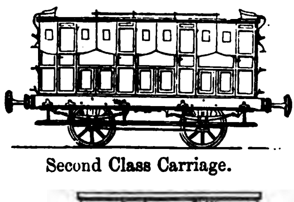
In the construction of the passenger carriages, one especial object should be kept in view. The proportion of the paying to the dead weight in passenger trains is susceptible of material modification, and consequent economy.

The travelling public, as a body, would not complain of a diminution in the luxurious accommodation afforded, by which the charges were sensibly reduced; and it is manifest, that if, in lieu of six persons occupying one carriage, eight can in the same space be conveniently provided for, the charges upon the larger number might, without loss to the Company, be reduced by from 20 to 30 per cent.

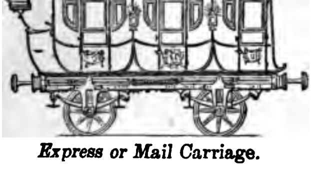
The annexed sketches of working stock consist of first and second class and mail carriages, luggage van, cattle and goods waggons, coal waggon, and timber carriage; the designs, dimensions, weights, and cost varying upon different lines.



First Class Carriage.

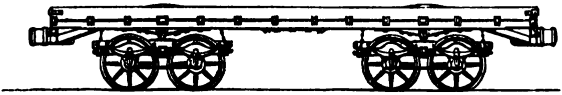


Second Class Carriage.

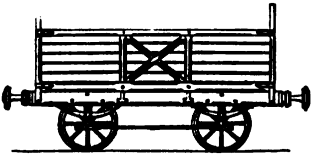


Express or Mail Carriage.

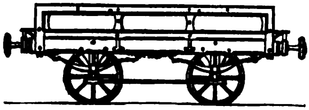
Luggage Van.



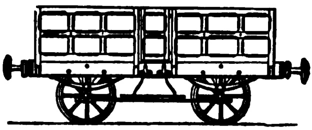
Timber Carriage.



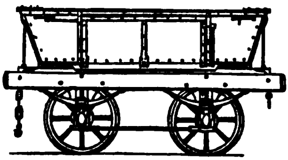
Goods Waggon.



Carriage Truck.



Third Class,
Open Passenger Carriage.



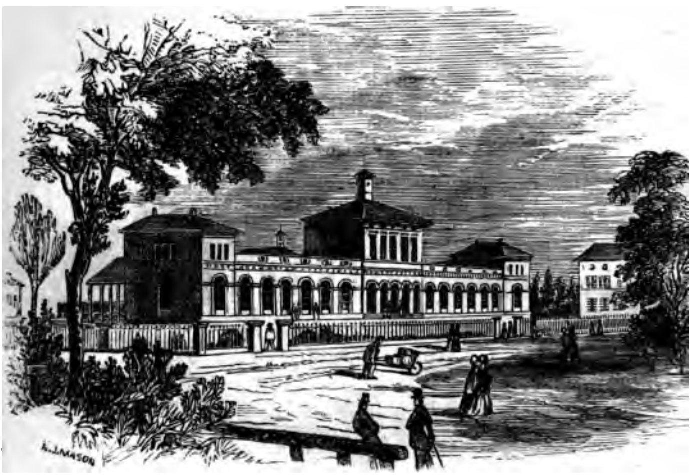
Coal Waggon.

DIVISION VIII.

STATIONS.

THE simple and economical character of the stations generally on the Continent and in America, are especially deserving of imitation, as structures which can at all times be enlarged, extended, altered, or rebuilt, without interruption to the traffic, and the ultimate dimensions and appliances of which cannot, in many cases, be determined until after the line has been for some time in operation.

The general character and appearance of the Continental stations, will be understood by reference to the accompanying sketches of the Taunus Railway.



Station at Francfort-on-Maine.

In signals and telegraphs there is little to be observed,

Station at Wiesbaden.

Station at Hochst.

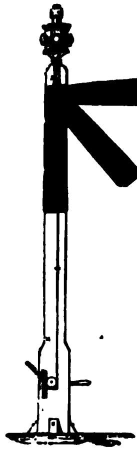
except that a preference appears due to the subterranean principle of conducting the wires, previously coated with gutta percha, in cast iron or other pipes over the plan in more general use :—the great objection of derangement from the electricity of the earth having been removed by the use of the double and oppositely charged needles on the same bearing. The Prussian telegraph system is of this description, and is found to work effectually.

Station at Cassel.

The basis of the signal system is simple. The three positions of a telegraphic arm by day, and the three colours of a lamp by night, comprehend the alphabet and vocabulary of ordinary practice. The diagram shows the distinction.

The *horizontal* arm, or the red light, intimates danger, *and the necessary* stoppage of the train.

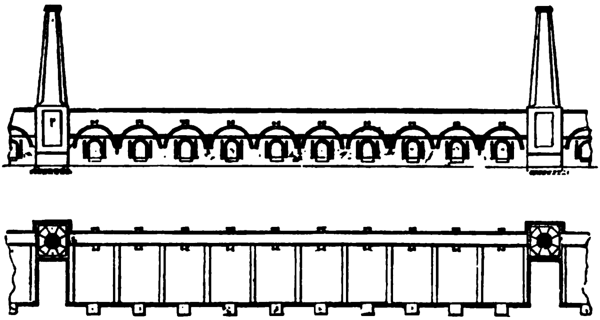
The intermediate position of the arm, or the green light, enjoins caution, and a diminished speed.



The dependent or vertical arm, or the white light, implies that no obstruction exists, and that the train may proceed.

The cost of coke must depend materially upon the facilities which are available for the supply, either from collieries in the country, or by import. In the latter case, the expense will of necessity be heavy. In the former, it will diminish in proportion to the proximity of the coal works to the Railway. When a line passes through or near a coal district, it will be desirable to build the coke ovens upon the spot. Arrangements for this purpose may be made with the coal owners to burn and supply the coke at a station on the line, or the ovens may be erected by the consumers, but the site should be selected where the carriage will add but little to the cost.

The form and principles of construction of the most improved descriptions of coke ovens are shown in the accompanying diagrams:—

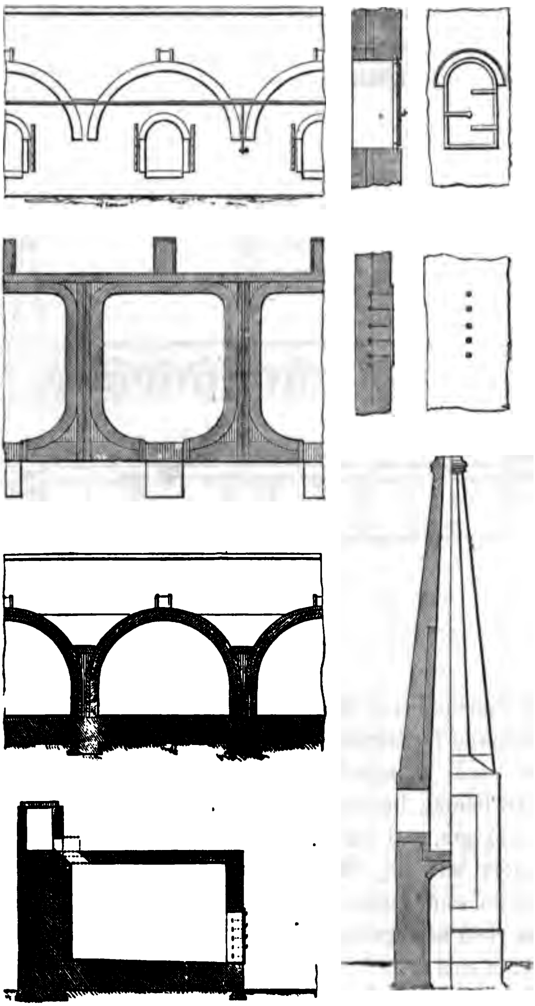


The dimensions of the coke ovens, their charges, and the time allowed for burning, vary upon all lines.

The usual charges are about 4 tons of coal, and drawn after 48 hours; but ovens have been constructed for 7 and 8 ton charges, and the time extended to 72 and 96 hours. By longer burning, the coke becomes harder, and is preferable for some engines.

The yield averages of good coke about two-thirds of the weight of coal.

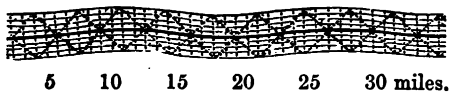
The diagrams show the largest sized ovens calculated for *8 ton charges*, and with the flues upon the most improved *construction*.

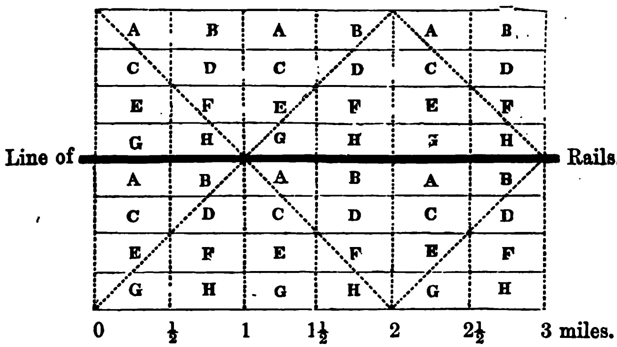


The annexed wood-cuts show the land lots adjoining the

Railway, and the direction of roads which converge at 2 miles distance along the line.

The letters indicate the eight divisions of 80 acres contained in each square mile.





The above is the illustration of a principle which will equally apply, whatever variation may be occasioned by local circumstances in any or all of the details, as the rentals will bear direct relation to the original outlay for purchase, improvement, government, rent, and superintendence.

DIVISION IX.

FORMS OF RETURNS & SPECIFICATIONS

CONSTRUCTION.

1	Expenses before Act	£
2	Land and compensation	,,
3	Contracts for works. A.	,,
4	Permanent way; timber, rails, and all materials. B.	,,
5	Locomotive engines and carriages, &c. C.	,,
6	Engine houses, tools, and machinery...............	,,
7	Engineering and surveying	,,
8	Advertising and printing	,,
9	Travelling expenses	,,
10	Law charges and conveyances	,,
11	Stamps for debentures	,,
12	Parliamentary expenses............................	,,
13	Maps, plans, &c.	,,
14	Office expenses, salaries, direction, postages, rent, &c.	,,
15	Discounts and commissions	,,
16	Electric telegraph	,,
17	Miscellaneous charges................................	,,
18	*Total cost of construction*	,,

WORKING EXPENSES.

			COST.
		Per mile.	
19	Maintenance of way	£	
20	Locomotive account, viz., coal, coke, repairs, wages, oil, tallow, and all incidental expenses. D.	,,	
21	Carrying account, viz., clerks, superintendents, &c. E.	,,	
22	General charges, viz., salaries, direction, and office charges. F.	,,	
23	Total working expenses	,,	
24	Government duty	,,	
25	Rates and taxes	,,	
26	Depreciation and replacing stock and plant	,,	
27	Total working expenses, duty, and depreciation.	,,	

RECEIPTS.

			COST.
28	Passengers	£	
29	Carriages, dogs, and horses	,,	
30	Cattle	,,	
31	Merchandise	,,	
32	Parcels	,,	
33	Rents and sundries.......................................	,,	
34	Mails	,,	
35	*Total Receipts*...	,,	

A. CONTRACTS POR WORKS.

		Cubic yds.	Rate.	COST.
36	Excavations....................		£	
37	Embankments....................		,,	
		No.	Length.	
38	Tunnels		,,	
39	Timber viaducts		,,	
40	Iron bridges, cast & wrought		,,	
41	Timber bridges		,,	
42	Stone bridges		,,	
43	Occupation bridges............		,,	
			No.	
44	Culverts, above 3 feet.................		,,	
45	Ditto, less than 3 feet		,,	
			Cubic feet.	
46	Timber not enumerated		,,	
			No.	
47	Terminal stations........................		,,	
48	Intermediate stations		,,	
49	Station engines		,,	
50	Tanks and water cranes		,,	
51	Miscellaneous		,,	
52	Average length of lead.......................			
53	Proportion of hard rock cut through in earthworks			
54	Proportion of earth and soft work in earthworks			
55	Proportion paid for materials			
56	Proportion paid for labour			
57	Total distance			
		Av.	St.	
58	Average and steepest gradients			
			No.	
59	Station signals and ticket apparatus for all stations		£	
60	Average cost per yard run of—			
	Excavations		,,	
	Embankments		,,	
	Tunnels.............................		,,	
	Timber viaducts		,,	
	Iron bridges		,,	
	Timber bridges.....................		,,	
	Stone bridges		,,	

B. PERMANENT WAY.

				COST.
		Cubic yds.	Rate.	
61	Ballast..........................		£	
		No.		
62	Stone sleepers...		,,	
63	Wood sleepers..................		,,	
64	Chairs		,,	
		Tons.		
65	Rails		,,	
			lbs. per yard.	
66	Weight and section of rails...			
		No.	Rate.	
67	Turntables		£	
		Qy.		
68	Switches, turnouts, sideings.		,,	
69	Bricks and drain tiles.........		,,	
70	Cast-iron drain pipes		,,	
71	Spikes and keys		,,	
		Yards.		
72	Telegraph wire and insulation...........		,,	
		No.		
73	Telegraph supports		,,	
74	Telegraph station apparatus		,,	
75	Telegraph fixing......................		,,	
76	Laying rails		,,	
77	Filling in ballast.......................................		,,	
		Qy.		
78	Coating under blocks and felt...........		,,	
		Yards.		
79	Fencing and quicks......................		,,	
80	Labour to fencing and quicks		,,	
81	Labour, miscellaneous		,,	

C. CARRYING STOCK.

		No.		COST.
82	Locomotive engines and tenders		£	
83	First class carriages........................		,,	
84	Second class ditto...........................		,,	
85	Third class ditto		,,	
86	Post office ditto		,,	
87	Luggage vans		,,	
88	Goods waggons.............................		,,	
89	Coal waggons		,,	
90	Horse boxes and cattle cages		,,	
91	Carriage trucks		,,	
92	Miscellaneous...		,,	

D. LOCOMOTIVE ACCOUNT.

93	Wages of engine men and firemen.................		£	
94	Waste, oil, tallow, water, and firewood		,,	
95	Wages, labourers, and cleaners.....................		,,	
96	Superintendents, clerks, salaries, and office charges		,,	
97	Repairs of engines and tenders		,,	
98	Coke..	cwt.	,,	
99	Incidental charges		,,	
100	Assistant engines, all charges together	No.	,,	
101	*Total locomotive* account		,,	

E. CARRYING ACCOUNT.

102	Salaries—Booking clerks, and petty disbursements .... £	
103	Wages--Guards and conductors .... ,,	
104	———Police and inspectors .... ,,	
105	———Switchmen, messengers, and porters... ,,	
106	Clothing .... ,,	
107	Carriage and waggon repairs .... ,,	
108	Stores consumed .... ,,	
109	Waste, oil, tallow, fuel, and carrying incidental expenses .... ,,	
110	Printing, stationery, and tickets .... ,,	
111	Lighting and gas at stations .... ,,	
112	Total carrying account for coach and merchandise traffic .... ,,	

F. GENERAL CHARGES.

113	Salaries .... £	
114	Advertising .... ,,	
115	Printing, stationery, ticket books, &c. .... ,,	
116	Medical expenses .... ,,	
117	Postages .... ,,	
118	Law charges .... ,,	
119	Travelling expenses .... ,,	
120	Sundry office expenses .... ,,	
121	*Total general* charges .... ,,	

COMPARATIVE RESULTS.

		Passengers.	Goods.
122	Average speeds............		
123	Average passengers per train		
124	Average weight of goods per train		
125	Average scale of charges per mile, passengers— First. Second. Third.		£
126	Average goods charges per ton per mile— First. Second. Third.		,,
		P.	G.
127	Average quantity of coke used per mile run		,,
128	Average cost of oil and tallow per mile run....................		,,
129	Average cost of repairs per mile run		,,
130	Average cost of coke per mile run		,,
131	Average engineers' and firemen's wages per mile run ...		,,
132	Average general charges per mile run		,,
133	Total cost per mile run		,,
134	Reconstruction per mile run		,,
		Passgrs.	Goods.
135	Total cost per train per mile run		
136	No. of miles run by each engine.......................		
137	Number of passengers carried — 1st Class. 2nd Class. 3rd Class		
138	Tonnage of goods carried— Tons. 1st Class. Tons. 2nd Class. Tons. 3rd Class.		
139	Total receipts, No. 35..................................		
140	Working expenses, No. 23		
141	Duty and rates, Nos. 24, 25		
142	Depreciation, No. 26		
143	Total expenditure, No. 27		
144	Profit		
145	Per centage of expenditure to returns, viz. :— *Working* Expenses. Duty. Depreciation. Total.		

ESTABLISHMENT.

146	Direction	
147	Local management	
148	London establishment.—Secretary and clerks	
149	Local establishment.—Secretary and clerks	
150	Engineers' departments.—Engineers, surveyors, and draughtsmen..	
151	Principal and intermediate station superintendents and clerks	
152	Repairing shops. — Superintendents, engineers, fitters, turners, founders, &c..........................	
153	Locomotive establishment.—Engine drivers, firemen, cleaners, &c.	
154	Carrying establishment. — Guards, conductors, clerks, porters, switchmen, police, warehousemen, signal men, &c.	
155	Construction of line.—Clerks of contracts, superintendents of works, labourers on line	
156	Maintenance of way.—Plate layers, bricklayers, labourers, of all descriptions, &c.	
157	Carriage and waggon construction department	

PAY LIST.

158	Detailed list of all classes employed by the Company	
159	Rate of pay of each class	
160	*Aggregate* pay of each class	

RETURN OF COST OF MATERIALS AND LABOUR TO BE FILLED UP FOR EVERY 10 MILES ALONG THE LINE OF RAILWAY REFERRED TO.

161	First Division.	Second Division.	Third Division.	Fourth Division.
A.—What description of stone is found				
B.—What does it cost delivered per 100 cubic feet				
C.—At what price can good bricks be delivered per 1000				
D.—What is the cost of brick masonry per 100 cubic feet, including all charges..........................				
E.—What is the cost of skilled and of common labour per month......				
F.—What description of timber is obtained in the neighbourhood ...				
G.—At what price delivered per 50 cubic feet........................				
H.—What does limestone cost per 100 cubic feet........................				
I.—At what price are rails and chairs delivered				
J.—At what cost are coals, coke, and charcoal obtained.....				

FORM OF RETURNS UPON MASSACHUSSETTS LINES.

Capital stock		
Increase of capital since last report		
Capital paid in, per last report		
Capital paid in, since last report		
Total amount of capital stock paid in		
Funded debt, per last report		
Funded debt paid since last report		
Funded debt, increase of, since last report . . .		
Total present amount of funded debt		
Floating debt, per last report		
Floating debt paid since last report		
Floating debt, increase of, since last report . . .		
Total present amount of floating debt		
Total present amount of funded and floating debt . .		
Average rate of interest per annum on ditto . . .		

Cost of Road and Equipment.

For graduation and masonry, per last report . . .		
For graduation and masonry paid during the past year .		
Total amount expended for graduation and masonry .		
For bridges, per last report		
For bridges, paid during the past year		
Total amount expended for bridges		
For superstructure, including iron, per last report . .		
For superstructure, including iron, paid during the past year		
Total amount expended for superstructure, including iron		
For stations, buildings, and fixtures, as per last report		
For stations, buildings, and fixtures, paid during the past year		
Total amount expended for stations, buildings, and fixtures		
For land, land-damages, and fences, per last report . .		
For land, land-damages, and fences, paid during the past year		
Total amount expended for land, land-damages, and fences		
For locomotives, per last report		
For locomotives, paid during the past year . . .		
Total amount expended for locomotives		
For passenger and baggage cars, per last report . .		
For passenger and baggage cars, paid during the past year		
Total amount expended for passenger and baggage cars		
For merchandise cars, per last report		
For merchandise cars, paid during the past year . .		
Total amount expended for merchandise cars . . .		
For engineering and other expenses, per last report . .		
For engineering and other expenses, paid during the past year		
Total amount expended for engineering and other expenses		
Total cost of road and equipment		

Characteristics of Road.

Length of road, [main road]
Length of single track
Length of double track
Length of branches owned by the Company, stating whether they have a single or double track
Weight of rail per yard in main road
Weight of rail per yard in branch roads
Maximum grade, with its length in main road
Maximum grade, with its length in branch roads
Total rise and fall in main road
Total rise and fall in branch roads
Shortest radius of curvature with length of curve in main road. [Radius 1,050 feet]
Shortest radius of curvature, with length of curve in branch roads, [Radius, 573 feet]
Total degrees of curvature in main road
Total degrees of curvature in branch roads
Total length of straight line in main road
Total length of straight line in branches
Aggregate length of truss bridges
Whole length of road unfinished on both sides

Doings during the Year.

Miles run by passenger trains
Miles run by freight trains
Miles run by other trains
Total miles run
Number of passengers carried in the cars
Number of passengers carried one mile
Number of tons of merchandise carried in the cars
Number of tons of merchandise carried one mile
Number of passengers carried one mile, to and from other roads
Number of tons carried one mile, to and from other roads
Average rate of speed adopted for passenger trains, including stops
Average rate of speed adopted for freight trains, including stops
Estimated weight in tons of passenger trains, including engine and tender, but not including passengers, hauled one mile
Estimated weight of merchandise trains, including engine and tender, but not including freight, hauled one mile

Expenditures for Working the Road.

For repairs of road, maintenance of way, exclusive of wooden truss bridges and renewals of iron
For repairs of truss bridges
For renewals of iron, including laying down
For wages of switch-men, gate-keepers, and flag-men
For removing ice and snow
For repairs of fences, gates, houses for flag-men, gate-keepers, switch-men, and tool-houses
Total for maintenance of way

MOTIVE POWERS.		
For repairs of locomotives		
For new locomotives, to cover depreciation . . .		
For repairs of passenger cars		
For new passenger cars, to cover depreciation . . .		
For repairs of merchandise cars		
For new merchandise cars, to cover depreciation . .		
For repairs of gravel and other cars		
Total for maintenance of motive power		
MISCELLANEOUS.		
For fuel and oil		
For salaries, wages, and incidental expenses, chargeable to passenger department		
For salaries, wages, and incidental expenses, chargeable to freight department		
For gratuities and damages		
For taxes and insurance		
For ferries		
For repairs of station buildings, aqueducts, fixtures, and furniture		
For interest		
For amount paid other companies, in tolls for passengers and freight carried on their roads, specifying each company, [Portland and Portsmouth Railroad Corporation]		
For amount paid other companies as rent for use of their roads, specifying each company		
For salaries of president, treasurer, superintendent, law expenses, office expenses of the above offices, and all other expenses not included in any of the foregoing items, [including loss on passenger cars and freight cars worn out and broken up, 5,000 dollars] .		
INCOME DURING THE YEAR.		
For Passengers:—		
1. On the main road exclusively, including branch owned by Company		
2. To and from other roads, specifying what:		
For Freight:—		
1. On main road and branches owned by Company .		
2. To and from other connecting roads:		
U. S. Mails, 6,098 dollars, 76. Rents, 3,182 dollars, 73 .		
Total income		
Net earnings after deducting expenses		
DIVIDENDS.		
[Two dividends: one paid in July, 4½ per cent.; one paid in January, 1849, 4 per cent.]		
Surplus not divided		
Surplus last year		
Total surplus		
ESTIMATED DEPRECIATION BEYOND THE RENEWALS, VIZ.:		
Road and bridges		
Buildings		
Engines and cars		

LONDON AND NORTH WESTERN RAILWAY.

SPECIFICATIONS OF STORES' QUANTITIES.

Bags, Baskets, and Ropes.—16 baskets, 1 bushel; 1,200 ditto to hold ½ cwt. of coke. 2,729 bags, ditto. 636 sheets, 2,000 square feet, felt, patent; 139 sheets ditto, tarred. 85 cwt. flax; 48 balls ditto, white; 0 ditto, spun. 220 lbs. hemp rope: 28 lbs. ditto, dressed; 92 lbs. ditto, green. 35 cwt. marline. 52 cwt. rope; 32 cwt. ditto, best white; 0 ditto, best tarred. 260 lbs. twine tufling. 2 cwt. tow. 560 lbs. twine, strong seaming; 368 lbs. ditto, middling; 224 lbs. Dutch; 0 ditto for stitching tarpaulins; 336 lbs. ditto tarred or pitched band. 60 cwt. yarn, spun.

Brass and Brass Work.—0 axle boxes, castings for. 1,000 feet beading, ½-inch. 0 bead frames. 0 bells, hand. 336 lbs. bushes. 336 bush sockets. 60 dozen bolts for sheets. 14 sets curtain rods and fixtures, bronzed. 12 gross curtain rings. 352 cwt. castings. 16 cocks, gauge; 8 ditto, cylinder cover; 8 ditto, blow off; 6 ditto, steam for pressure gauge; 24 ditto, pet, with union joints, complete; 16 ditto, mud; 16 ditto, tallow. 18 dozen escutcheons. 6 dozen glass string fasteners; *6 dozen ditto* guides. 0 handles, ventilator, flush; 42 pairs *ditto, 1st class* door; 110 pairs ditto, ditto, re-plated; 42 pairs

dozen hinges, $3\frac{1}{2} \times 2\frac{3}{8}$, $2\frac{1}{2} \times 2\frac{3}{8}$, $2 \times 2\frac{3}{8}$; 24 dozen ditto, lamp protector. 432 knobs on plates. 144 plates for door stops; 72 ditto, fence; 144 ditto, lap; 72 ditto, bottom; 0 ditto, name to pattern. 1,428 lbs. sheet. 144 gross screws. 7 gross staples, hat string and door stop. 0 spring balances, Salter's patent, best description, say round. 0 60 lb. balances, varying in range from 8 to 10 inch; 0 70 lb. ditto, ditto; 12 80 lb. ditto, ditto; 0 90 lb. ditto, ditto; 0 100 lb. ditto, ditto; 0 120 lb. ditto, ditto; 0 140 lb. ditto ditto; 50 90 lb. ditto, flat $6\frac{1}{4}$ inches. 0 syphons, flange, large; 0 ditto, small; 0 ditto, large ball; 0 ditto, small ball. 4 tons steps. 59 tons tubes, locomotive; to be made from the very best material, and to be sufficiently strong to keep themselves straight when put in the boilers; to be made to dimensions; and to be proved with an internal pressure of 300 lb. on the square inch, any diameter, length, and gauge. 0 ventilator brasses. 5 lbs. wire, $\frac{3}{16}$ round. 224 lbs. wire to sizes. 12 whistles.

Brushes, Brooms, Mops, Mats, Pencils, &c.—36 brushes, dusting, 0000; 6 gum; 24 long-handled; 0 cushion; 36 black-lead, round; 120 stove; 324 spoke; 0 buffer; 24 scrubbing, &c., &c.; 0 hearth; 0 oil, round; 72 body; 144 banister; 480 sash tool 3, 4, 5, 6, 7, 8, 10, 12; 216 ground 0000; 336 sweeping; 0 steel wire; 240 paint; 24 sheet. 1000 dozen brooms, birch; 9 whalebone; 34 hair; 18 banister; 1 carpet. 36 mats, door; 0 horse box. 28 dozen mops, wool; 0 rag. 37 pencils, duck liners, sable, &c. 0 rugs, carriage; 0 guards.

Copper.—8960 lbs. bolt, from $\frac{1}{2}$ to $1\frac{1}{2}$ inch diameter. 28 lbs. brads, 1 inch. 2240 lbs ingot. 336 lbs. pipe. 112 lbs. rivets, 11,200 lbs. sheet, various thicknesses and dimensions; 12,768 lbs. ditto for fire-boxes, $\frac{3}{4}$ and $\frac{1}{2}$ inch, and

to dimensions; 0 ditto shaded to sketches. 392 lbs. wire to sizes. 84 lbs. washers.—(The above to be of the best tough copper.)

Coach Trimmings, Carpeting, Cloth, Canvas, Flannel, &c.—0 binding, green. 120 yards bunting. 350 yards carpet, Brussels. 4300 ditto canvas for sheets, to sample; 500 yards ditto for roofs, ditto; 6000 yards ditto for glueing, ditto; 800 yards ditto for beetler, ditto; 200 yards ditto for dowlas, ditto; 500 yards ditto for derrys, ditto; 400 yards ditto for No. 6, ditto; 350 yards ditto for No. 2, ditto. 1040 yards blue, ditto. 100 yards damask, green. 0 ditto, cloth. 12 dozen dusters, linen. 12 dozen flannel, house. 6 dozen flags, white; 27 dozen ditto, red; 10 dozen ditto, green. 46 dozen hat strings. 480 holders and glass strings. 8460 yards lace, seaming; 2840 yards ditto, binding; 860 yards ditto, pasting. 930 square yards oil cloth, roof; 0 ditto, imitation morocco. 240 dozen roses. 40 yards silk, green; 300 yards ditto line. 30 gross tufts; 0 ditto daisy, with strings. 29 lbs. thread, drab; 29 lbs. ditto, white. 6 dozen towels, diaper. 30 yards, velvet, black. 40 yards worsted cord. 1500 yards webbing.

Coal, &c.—11,926 tons coal,* large; 1223 tons ditto, Smith's; 1820 tons ditto, cobbles; 2680 tons ditto, slack; 1 ton ditto, dust. 454 tons cannel, for gas. 2985 tons coke,† Smith's.

* LARGE COALS	Crewe . . .	2500	tons
,,	Edge Hill . .	3950	,,
,,	Preston . . .	680	,,
,,	Manchester . .	190	,,
† SMITH'S COKE	Crewe . . .	960	,,
,,	Edge Hill . .	200	,,
,,	Preston . .	200	,,
,,	Manchester . .	35	,,

Crucibles for Moulding Brass.—To be made from the best clay, and warranted to stand the heat of the furnace for at least one whole day.—304 pots to hold 40 lbs. metal; 618 ditto 50 lbs. ditto; 545 ditto 60 lbs. ditto; 0 ditto 70 lbs. ditto; 422 ditto 80 lbs. ditto; 300 ditto 90 lbs. ditto; 350 ditto 100 lbs. ditto.

Colours, Varnishes, and Drysaltery.—2½ cwt. black lead, in ½ lb. packages. 0 bronze, green. 414 lbs. borax. 672 lbs. Bolton polish. 2½ cwt. chrome yellow. 0 copperas, green. ½ cwt. Chelsea red. 0 Dutch pink. 5½ cwt. drop black. 22 cwt. dryers, patent, best quality. ¾ cwt. emery powder, Nos. 2 and 3; ½ cwt. ditto, No. 1. 65 reams ditto cloth, best quality. 4 cwt. gum. 262 gallons gold size. 110,000 leaves gold leaf, large pale; 2500 leaves ditto, ditto deep. 44¾ cwt. glue. 31½ green, Brunswick; 2 cwt. ditto, quakers. 0 ivory black. 58 lbs. lake, crimson. 22 cwt. lamp black, common; 6 casks ditto, best vegetable. 0 ochre, spruce; ½ cwt. ditto, yellow; 13 cwt. ditto, brown. 13 cwt. paint, black; 20 cwt. ditto, mineral tar; 8 cwt. ditto, lead, coloured; 22 cwt. ditto, green; 120 cwt. ditto, white; 60 cwt. ditto, protoxide (Todd's). 17 cwt. putty, best linseed oil and whiting in proper proportions, coloured if required. 560 lbs. Prussian blue, ground. 1½ cwt. potash, prussiate of. 1½ cwt. potash. 0 pipe-clay. 35¼ cwt. pumice stone, lumps. ¾ cwt. rotten stone. ¾ cwt. resin. 99 cwt. red lead. 5½ reams sand paper. 5½ cwt. sugar of lead. 52 cwt. soda. 1 cwt. umber, common English; 0 ditto, burnt. 192 lbs. vermilion, English; 62 lbs. ditto, Chinese. 256 gallons varnish, carriage; 500 gallons ditto, body; 42 gallons ditto, filling up; 252 gallons ditto, japan black; 10 gallons ditto, black naphtha; 10 gallons ditto, red; 16 gallons ditto, copal. 465 cwt. white lead, first quality; 27½ cwt. ditto, ditto,

dry. 33 cwt. whiting. 48 lbs. wax, shoemakers'. 32 lbs. wax, bees'.

Iron and Iron Work.—0 anvils—Hill's, P. Wright's, or Sanders' make, well steeled and hardened, and warranted for twelve months from time of delivery. 24 augers. 35 tons axles, carriage, hammered Yorkshire iron; 573 cwt. ditto, guards; 150 cwt. ditto, moulds; 125 ditto, patent shaft waggon, or Lowmoor, to dimensions, and template; 0 ditto, common rolled, of scrap iron; 0 ditto, ditto, of bowling iron; 0 ditto, not turned. 16 cwt. bar iron, best hammered; 50 tons ditto, patent shaft; 190 tons ditto, fire or grate. 42½ tons bolts, S. C. iron (various); 0 ditto, boot door. 13 tons bolts and nuts, S. C. iron and approved thread; 0 ditto ditto, to be made from best iron. 0 boxes, axle. 4½ cwt. brads, inch. 90 cwt. brake, guards; 200 ditto, shoes; 0 ditto screws; 0 ditto waggon steps; 2 dozen ditto, door locks; 2 dozen ditto, chest locks; 328 cwt. ditto, levers of approved workmanship; 0 ditto, work to pattern. 80 cwt. buffer head moulds; 0 ditto hooks, S. C. iron. 0 ditto rods, ditto, to pattern; 10 cwt. ditto shoes, ditto. 102 tons castings, No. 1, best metal; 2½ tons ditto, malleable iron. 200 yards (700 cwt.) chain, coil, of approved quality; 18 cwt. ditto, crane, to be short linked, made of the best cable chain iron, and tested to standard weight; 240 cwt. ditto, coupling and hooks, best possible quality, of patent shaft iron, warranted; 120 yards ditto, dog; 0 ditto, side, to pattern, of best scrap iron; 30 cwt. ditto, bolster. 0 connecting rods, S. C. iron. 0 corner plates, S. C. iron. 90 gross cotters, split. 40 cwt. charcoal plate. 0 draw bar ends, best. 200 grease covers, best charcoal plate. 0 handles for brakes. 78 hammers, hand, well steeled and hardened; 0 ditto, sledge. 96 pair hinges, butt, cast according

to sizes; 200 pair ditto, ditto, wrought ditto; 0 ditto, footplate ditto; 0 ditto, box; 36 pair ditto, cross garnet. 0 hooks, can; 0 ditto, dog; 0 ditto, grab; 0 ditto, hand; 0 ditto, lead; 18 cwt. ditto, sheet; 0 ditto, timber. 0 hooks, truss; 0 ditto, wool; 0 ditto, yoke. 48 tons iron, Lowmoor or bowling. 0 iron work, wrought for horse boxes. 10 dozen keys, locker. 100 cwt. knees, S. C. iron. 5 dozen knives, grease. 12 dozen keys, carriage door. 12 locks, door; 96 ditto, cupboard and box; 12 dozen ditto, pad; 90 dozen ditto, spring box, large; 9 dozen ditto, ditto, small; 14 ditto, patent waggon. 0 lamp irons; 0 ditto, small. 0 moulds, S. C. iron. 1 cwt. nails, 4 inch, rose head and clasp, of approved quality; 43 cwt. ditto, $2\frac{1}{2}$ inch ditto; 88 cwt. ditto, assorted; 5 cwt. ditto, *2d.* and *3d.* clouts. 0 name and number plates, of malleable iron. 200 gross nuts, $\frac{3}{8}$ and $\frac{3}{4}$ inch. 140 mille panel pins, inch and $\frac{1}{2}$ inch. 2 cwt. pig-rail hoops; 0 ditto pins; 0 ditto studs. $\frac{1}{2}$ cwt. pins, coach, assorted. 60 tons pig iron, Staffordshire, various Nos. 0 pig iron, Welsh, various Nos. 0 ditto, Shropshire, ditto. 0 rakes. 69 cwt. rivets, good quality. 6 saws, various sizes; 24 ditto blades. 36 pair scissors. 0 scrap iron, rolled. 6360 gross screws, for wood, of best quality. 9 cwt. screws, coach, of best quality. 41 screw jacks (to sample). 4 dozen scuttles, coal. 0 shackles, spring; 302, ditto of best Lowmoor iron. 280 tons Staffordshire iron, best rolled; 233 tons ditto, in bar, flat, square, round, and rod; 6 tons ditto, hoop; 61 tons ditto, sheet; 33 tons ditto, plates; 9 tons ditto, angle; 30 tons ditto, axles, straight (patent); 6 tons ditto, ditto, cranked; 172 tons ditto, tire bars, according to weight. 6 dozen shovels; 389 ditto, fire, for locomotive engines; 131 ditto, for cokemen; 24 ditto, for moulders. 0 steps to pattern. 2 tons staples, S. C. iron; 1 ton ditto, draw. 0 slings, chain. 200 slide rollers. 200

spring fasteners, S. C. iron. 1 dozen spuds (straight). 1 dozen stoves (to sample). 1278 mille 3½ cwt. tacks. 100 ticket holders. 0 tires, Lowmoor and Bowling. 1 ton uses or forged iron work. 0 vices, to be the best bright patent washer vices, with counter threads, and warranted for twelve months from time of delivery. 10 cwt. 20 gross washers, Staffordshire plate. 4 cwt. ditto, ⅜ in. ½ in. ⅝ in. ¾ in.; 230 gross (60 cwt.) ditto various. 300 sets wheels, new, to specifications and drawings, at per set of 4 wheels and axles. 80 sets wheels, re-tired, Lowmoor or Bowling, 4½ in. and 5 in. wide, and 1¾ in. thick. 70 sets wheels, chilled; 0 ditto, truck; 250 ditto, centres, cast to sample, large; 250 ditto, ditto small. 10½ cwt. wire, to size. 430 feet wire gauze. 84 wrenches, monkey, best description; 0 ditto, screw. 0 Yorkshire bars, best, 0 ditto, flat; 13 tons ditto, square; 0 ditto, round; 0 ditto, rod. 0 Yorkshire, best, hoop; 15 tons ditto, sheet; 0 ditto, ditto, cut to section; 15 ditto, plates; 0 ditto, hammered; 4 ditto, angle, 0 ditto, axles, straight; 0 ditto, ditto, cranked; 120 ditto tire bars, according to weight.

Lamps and Lamp Materials.—12 gas consumers. 24 lamps, buffer; 0 ditto, tender; 20 ditto, gauge; 0 ditto, gauge and hand; 36 ditto, guards; 0 ditto, tail signal; 0 ditto, roof; 96 ditto, hand; 72 ditto, tricolour; 0 ditto, side; 0 ditto, gas lighters'; 0 ditto, station signal; 0 ditto, reflectors, plated; 200 ditto, irons, small; 56 lbs. ditto cotton (to sample); 48 gross ditto, solar; 12 gross ditto, Argand. 132 lbs. lamp cotton, ball; 100 gross ditto ditto, tape; 0 ditto glasses; 12 ditto glasses, globe; 12 gross ditto ditto, solar chimneys; 0 ditto ditto, Argand; 2 dozen ditto ditto, bent red; 2 dozen ditto ditto, bent green; 132 boxes ditto wicks, wax; 0 ditto,

ditto, round; 0 ditto, ditto, flat; 0 ditto, ditto, long; 60 ditto rings, roof; 200 ditto, block rims; 0 ditto blocks; 0 ditto signal glass, white, cut to sizes; 0 ditto ditto, green; 0 ditto ditto, red, cut to sizes.

Leather, &c.—0 bags, cash. 0 belts, guards'. 224 lbs. belt. 224 lbs. buffer. 0 cases, flag. 0 leggings. 1344 lbs. cuttings, 25 hides double straps. 12 pairs glass strings, bridle middlings. 1900 feet hose pipes, patent, to any length or size. 132 horse head collars. 0 hides (rounded), to sample; 1456 lbs. ditto, harness, ditto; 1060 lbs. ditto, white horse ditto. 6 dozen kip. 2044 lbs. pipe and buffer. 10 dozen skins, morocco, claret; 5 dozen ditto, ditto, blue; 4 dozen ditto, calf; 2 dozen ditto, brown bazils; 156½ dozen ditto, chamois. 1060 lbs. strap, hides for machinery; 1600 ditto, luggage. 392 lbs. sole, butt. 100 lbs. white. 0 washers, axle box.

Oil, Tallow, Candles, Turpentine, and Waste.—36 lbs. candles, composition; 8¼ cwt. ditto, best store; 55 cwt. ditto, green dips. 31,652 gallons oil, patent olive, samples to be sent with tender; 142 tons 15 cwt. ditto, rape, best refined, suitable for locomotive engines, to be free from acid; 4 tons 10 cwt. ditto, linseed, best raw; 25 tons 9 cwt. ditto, boiled; 2350 gallons ditto, Southern; 28 tons ditto, palm; 54 gallons ditto, neats' foot; 6 flasks ditto, salad. 102 tons tallow, St. Petersburgh, picked, Y. C. 10¾ tons turpentine, best English. 250 gallons tarpaulings, mixture for. 86 tons waste, cotton, for cleaning engines (clean rough samples to be sent with tender); 26½ tons ditto, ditto, white, best quality.

Steel and Steel Work.—379 files, best warranted (cast), for

mechanics, of all sizes and descriptions, and of full standard weight (discount off list); 4 dozen ditto, saw. 102 dozen piston rings, best, warranted 15$\frac{1}{8}$ in.; 6 sets ditto, ditto, 14 in. 6 sets steel, best warranted, cast, for turning tools; 165 cwt. ditto, ditto, for taps and dies; 9 cwt. ditto, ditto, for chisels; 9 cwt. ditto, ditto, double shear steel; 19 cwt. ditto, ditto, common shear steel; 10 cwt. ditto, ditto, single shear steel, first quality; 8 cwt. ditto, ditto, ditto, common; 5 cwt. ditto, ditto, blistered, best quality; 45 cwt. ditto, ditto, spring $\frac{3}{8}$ and $_{16}$; 34 tons ditto, ditto, octagon; 0 ditto, ditto, key and drift. 10 cwt. steel, best warranted ferule, flat or bevelled; 33 cwt. ditto, ditto, spring, selected, manufactured from Swedish iron; 0 ditto, best warranted, cast piston rods; 0 ditto, ditto, slide bars; 0 ditto, ditto, cast chisels; 0 ditto, ditto, drills; 50 cwt. springs, best, warranted, engine; 40 cwt. ditto, ditto, tender; 340 sets ditto, ditto, bearing, to pattern; 105 sets ditto, ditto, buffer, ditto; 200 sets ditto, ditto, draw bar; 3 tons ditto, ditto, horse box and truck; 4 tons ditto, ditto, spiral; 0 ditto, ditto, elliptical; 380 sets ditto, ditto, patent buffer.

Timber and Wood Work.—19,367 feet alder planks, 3$\frac{1}{4}$ in. 4 in., 4$\frac{1}{4}$ in., various lengths and widths. 0 ash ribs, bent by steam. 600 cubic feet alder planks. 0 ash logs; 145 loads ditto planks. 40 loads birch logs; 0 ditto planks. 10,000 feet baywood boards. 0 boxes, guards'; 0 ditto, lamp. 0 barrows, luggage basket. 460 buffer blocks, 3 × 14 circular; 300 ditto socket, to pattern. 0 boards, tail and signal. 0 beech timber. 250 bundles chisel rods, best tough. 2000 deal battens, best Gottenberg. 91,000 feet super deal boards, yellow 1 in., 1$\frac{1}{4}$ in., and 1$\frac{1}{2}$ in., of best and second quality; and 3 in. by 11 in. best crown Archangel plank, dry, and free

from knots, saps, and shakes, both of 9 in. 11 in. wide, in 21 feet lengths. 2400 cubic feet deal battens, Archangel; 500 ditto planks; 6000 cubic feet (1500 feet super) ditto Dantzic, best quality; 0 ditto red. 40 loads elm logs, American, best quality; 0 ditto, English. 0 felloes. 24 dozen file handles, ash or beech. 36 dozen hammer shafts; 310 dozen ditto handles, best sledge, ash, dressed to pattern, free from knots and shakes; 24 dozen ditto hand, ash, ditto. 0 ladders, 12 round; 0 ditto, 14 ditto; 0 ditto, 15 ditto; 0 ditto, 16 ditto; 0 ditto, 18 ditto; 0 ditto, step; 0 ditto, lamplighters'. 18 levers. 0 limewood butts. 4 mahogany logs. 0 oak logs; 0 ditto butts; 0 ditto staves; 6000 cubic feet ditto, English, well seasoned, sound, and clean; 3000 cubic feet ditto, American, ditto, best white; 25 loads ditto, plank. 1500 pig rails; 1000 ditto, posts. 0 pine logs; 100 ditto planks. 8 loads poplar or willow planks. 12 pails. 5000 feet square, 6000 feet cubic pine boards (yellow), perfectly seasoned, dry, clean, and bright, of first-rate quality, and free from sap and shakes in boards, 11 in. wide, ½ in., ¾ in. thick; 0 ditto 11 in. wide, 1 in., 1¼ in., 1½ in., 1¾ in., 2 in.; 0 ditto 11 in. wide, 2¼ in., 2½ in., 3 in., 3½ in., 4 in. 80 loads pine pitch, best quality; 20 loads ditto, yellow, ditto. 3200 poplar brake blocks, best, cut to pattern, 4 in. thick, to be free from shakes, and all other defects, each (according to size or average); ditto, 3½ in, thick. 2500 elm ditto, ditto. 0 pine laggings, to be 2 in. wide and 1 thick, to be cut from dry and well-seasoned boards, free from knots, shakes, &c.; to be planed, grooved, and finished to pattern; to vary in lengths from 8 to 14 feet. 3352 feet ditto lagging board, 1¼ in. 0 quarter sweeps. Scantlings, best English oak or ash, cut to the following sizes, die square, free from sap, shakes, knots, and selected straight, &c., free from all defects:—5000 ft. cube,

of all dimensions, 7 ft. by 16 in. by 6 in.; 7½ ft. by 12 in. by in.; 8 ft. by 24 in. by 6 in.; 7 ft. by 12 in. by 6 in.; 8 ft. by 15½ in. by 6 in.; 8 ft. by 15½ in. by 6½ in.; 14 ft. by 11½ in. by 3¾ in.; 6 ft. 6 in. by 11½ in. by 5 in.; 7 ft. by 16 in. by 9 in.; 4 ft. 6 in. by 11½ in. by 4¾ in.; 4 ft. by 9 in. by 3¾ in.; 7 ft. 6 in. by 16 in. by 6 in.; for carriage buffers; 11½ in. square, for ditto, 16,000 feet super ditto oak, well seasoned, free from knots, shakes, and sap, of all dimensions; 8000 feet super ditto, American. 0 pitch pine ditto (St. John's). Sycamore, best English, in plank, selected straight and clean, free from all shakes, &c., and all other defects:—30,000 feet, of all descriptions, in planks, 1 in., 1½ in., 2 in., 2½ in., 3 in., 3½ in., 4½ in., 5 in. 0 sticks, flag. 8 gross scotches. 0 steps, private carriage. 0 stands, lamp. 0 willow butts. 0 yokes.

Tin, Zinc, Lead, and other Metal.—0 lead, ingot; 34 cwt. ditto, sheet; 114 cwt. ditto, pig. 126 cwt. patent white metal, Fenton's (castings); 2 cwt. ditto, Babbitt's; 0 ditto castings. 4 dozen paint kettles, double B. tin, 3 pints; 4 dozen ditto, 3 quarts. 8 cwt. spelter, coarse; 0 ditto, fine. 116 cwt. tin, block, best. 600 sheets tin, x x single; 1211 sheets ditto, x x x double. 72 ditto cans, grease, 36 ditto, water; 12 ditto, oil, 10 gallons. 0 ditto, funnels; 11 dozen ditto, feeders; 0 ditto, dust pans. 0 oil tanks, with 2 cocks and union joints, complete; 0 ditto, with 3 ditto; 0 ditto, with 4 ditto; 0 ditto, with 5 ditto. 0 zinc, ingot; 0 ditto sheet.

Sundries.—12 aprons, washers, to pattern. 4 gross buckles, japanned roller, 1½ in. 0 binding, blue. 24 buckets, gutta percha; 72 ditto wood. 27 gross congreves, boxes of. 0 carriage covers, various sizes. 1½ cwt. chalk. 0 glass plate, to pattern and sizes; 2628 feet ditto, plate; 12 reams ditto

paper; 1, 2, 3, best quality; 13 cwt. ditto gauge glasses for locomotive engines, to any length or diameter, to be of Newcastle make, well annealed. 0 glass, various; 4 dozen ditto, tumblers; 6 ditto, water bottles. 0 gutta percha belts, best, to any width, length, or thickness. 0 handles for brakes. 70 cwt. hair, curled. 96 dozen ivory studs and nails. 0 knobs, or bronzed plates. 1 cwt. links, pitch. 1 dozen needles. 28 reams paper, cabinet, Nos. 1, 2, 3. 12 dozen polishing paste, pots. 4 cwt. pitch. 31 pieces ribbon, China. 60 pieces sponge, best; 62 pieces ditto, middling quality. 0 springs, ventilator. 215 dozen signals, fog. $14\frac{3}{4}$ cwt. soap, brown, 1st quality; 211 firkins ditto, soft; 2 cwt. ditto, curd; 3 cwt. ditto, yellow. 18 dozen stones, hearth. 5 barrels tar, Stockholm.

DIVISION X

PERMANENT WAY.

CHAPTER I.

The cost of maintaining the permanent way, and of maintaining and working the trains, was about one-half as much on English as on American lines, and the economy of the former was due chiefly to smoother and more permanent road, bed, and superstructure. The excessive first cost of the British railway system was shown to consist chiefly in land and parliamentary expenses; in tunnels, bridges, viaducts, and stations, far exceeding in magnitude and cost the actual requirement of, at least, American lines, and in other items which do not contribute to the economical movement of trains. The simple "track" of a first-class English line was found to have cost about £300 per mile more than that of an ordinary American line, at the respective prices of materials and labour in the two countries. The American system, in virtue of its cheapness, has developed a considerable extent of country, which might not at this time have been opened to commerce had the expense of constructing an English system of railways been the sole condition of that development. On the other hand, the most poorly and cheaply constructed railways have not only required a constant expense for maintenance, which has sometimes consumed their entire earnings, but they have constantly depreciated to such extent as to precipitate ruin. Without referring to extreme cases, it is sufficient to mention that by this time it is well understood

—1st, that the original cost may so magnify the capital account, that the profits, however small the working expenses may be, will yield but a meagre dividend; 2ndly, that the working expenses of a cheaply constructed line may so much reduce the same gross amount of earnings as to leave an equally small per-centage of profits to the shareholders.* In 1855, when many of the railways of the State of New York were comparatively new, the repairs of permanent way amounted to 6·75 per cent. of its cost; and of equipment, to 14 per cent. of its cost, not to speak of depreciation. Facts clearly show that there must be for general purposes a system of railway construction, intermediate in excellence and cost between what are known as the European and the American systems; a combination, or, it may be, various different combinations of improvements and adaptations, which will decrease working expenses in a greater ratio than they can possibly increase first cost.

Such are the outlines of the problem which is at this time in the process of solution, and it would be as absurd to attempt a definite specification of the best permanent way until the problem is more nearly worked out by the general practice, as it would be to conclude that no improvement should be attempted in default of such a specification. While the financial condition, the credit, the traffic, the necessity of using what funds can be at present raised, in completing connections and perfecting business arrangements and other important considerations, must to a considerable extent decide the amount and the rapidity of the physical improvement of railways, it is at the same time perfectly clear that a moderate amount of ballast, better

* Not so with the Utica and Syracuse railroad, producing to the shareholders a good dividend whilst in progress of completion, but paying also current expenses of permanency in construction.—"Ensample of Railway," 8vo, 1843: London.

drainage, better rail, and some system of joint-fastenings, at least, are imperatively demanded in all cases. It will further appear that the most durable structures are not always the most expensive. Rails, for instance, of excessive weight and poor material, cost more per mile, although less per ton, than lighter rails of better material, which will last longer.*

EARTHWORK, DRAINAGE, AND BALLAST.†

The earthwork is the foundation and support of the whole superstructure, and as such must be uniformly firm. English and Continental engineers seek this condition by giving much care to the material, preparation, form and drainage of earthwork. As no excellence of superstructure can compensate for the evils of insufficient earthwork, or those occasioned by standing or running water, or by frost; foreign engineers allow very liberal widths of formation level, easy slopes, and ample ballast, while they provide the most thorough arrangements for the removal and exclusion of water.

Formation level.—The width of earthwork of double lines of roads of ordinary gauge is generally 33 feet in cutting and embankment. The earthwork of New York railway of the same gauge, is reported to the State railroad commissioners as follows: Average width for single lines, in cuttings 18 feet; banks 13 feet; for double lines, in cuttings 31 feet; banks 26·7. The extremes being in cuttings 25 and 40; banks 23 and 30, the width of road-bed may be taken as the measure of the comparative stability of the different lines. A serious defect in the construction of most American railways is the want of sufficient bearing surface of the sleepers. The English lines

* "American and European Railway Practice," by A. L. Holley, 4to, *New York, 1861.*
† Idem.

have generally 6 feet to 6 feet 6 inches between the two lines of double track, leaving from 7 feet to 8 feet 6 inches for the side spaces. The width of the side spaces leaves room for a shelf between the edge of the ballast and the ditch, so that any wash from the surface of the road-bed is prevented from passing into and choking the ditches; a similar level space is usually left in cuttings between the outside of the ditch, and the foot of the slopes themselves, to catch the wash from the upper surfaces. The same feature has been applied to a few American lines in cases of extreme necessity, as in some of the deep cuttings on the New York and Erie railway. In France it was formerly the practice to make very narrow earthwork, but to secure its stability by artificial protections. Thus, in cuttings, the road-bed at formation level would be perhaps 20 or 22 feet for double track, the two lines being from $4\frac{1}{2}$ to $5\frac{1}{2}$ feet apart, and the ballast being held between two dwarf walls, which also formed the insides of the ditches. The ditches being stoned on both sides, took very little space for width. The slopes would be a rough pavement, these abutting below against the outer wall of the ditch, with occasional arches thrown across against the side of the road-bed for strength. The present standard widths of earthwork for the new double lines of roads of 4 feet $8\frac{1}{2}$ inches gauge in France may be taken as follows:

Width between side drains	30 ft. 10 ins.	(9m. 40c.)
„ of ballast	27 „ $6\frac{3}{4}$ „	(8m. 40c.)
„ between centres of inner rails	6 „ $6\frac{3}{4}$ „	(2m.)
„ of ditches at top	4 „ 11 „	(1m. 50c.)
„ „ bottom	1 „ $7\frac{5}{8}$ „	(50c.)
Depth of ballast	1 „ $7\frac{5}{8}$ „	(50c.)
„ ditches below top of ballast	3 „ $3\frac{3}{8}$ „	(1m.)

Slopes.—The transverse slopes of English railway earthwork are of variable angles, according to the nature of the

soil and the height of the slope. They average much flatter, however, than on American lines. The following may be taken as approximate allowances for the former:

Gravel, sand, or common earth, cuts or banks of less than 4 feet	1	base to	1	vert.
Clay, cuts or banks of less than 4 feet . .	2	„	1	„
Earth, of mixed sand and clay, cuts or banks of 4 to 15 feet	1½	„	1	„
Pure gravel or sand, cuts or banks of 4 to 15 feet	2	„	1	„
Clay, in banks of 4 to 15 feet	2	„	1	„
Stratified clay and sand, cuttings of 4 to 15 feet	3	„	1	„
Broken rock, in banks over 15 feet high .	1½	„	1	„
Earth of mixed sand and clay, cuts or banks over 15 feet high	2	„	1	„
Pure gravel or sand, cuts or banks over 15 feet high	2	„	1	„
Clay, cuts or banks over 15 feet high . .	3	„	1	„
Stratified clay, in cuttings over 15 feet high	3 to 4	„	1	„

Cases exist of steeper slopes than those named above, while others are found where even flatter slopes are adopted. On the Newcastle and Carlisle railway, for 62 miles, all the slopes of 1½ to 1—a remarkable cutting through Corvran Hill, on that line—are 110 feet deep through sand, interspersed occasionally with thin seams of clay, and the slopes have stood well for many years. Cuttings on the Birmingham and Gloucester line, 50 feet deep in pure gravel, have stood well at 1 to 1, and on the same line is a cutting 86 feet deep, with a spoil bank on top of 24 feet, making a total depth of 110 feet in gravel and sand which has stood at 1½ to 1. On the other hand, a slope of 2 to 1 is adopted on many lines for even the shallowest cuttings in good material. Clay, which has stood well at 2 to 1, has often slipped at 6 to 1. In cases, however, of steep slopes, the bottom is often supported by a low retaining wall, or revetement of stone or earth.

While varying the angle of the slopes, to meet economi-

cal considerations, it is extremely important to take into account the direction of the strata, the direction of the line, circumstances of moisture, &c. In stratified soils, the slope would be made flatter than in homogeneous earth. Alternate strata of clay and sand are notoriously treacherous; the same earths mixed are much better. Separate strata will not absorb water and swell equally; any comparatively impervious seam, like clay, will confine the saturation to perhaps a single stratum. This swells and moves forward to the face of the slope, the movement being on the surface of the stratum below, which thus serves as a floor. After this movement between strata has once commenced, the slope is permanently weakened, and requires close attention. In inclined strata one slope would be naturally made flatter than the other. In a curve, the convex slope, being less self-supporting, should be flatter than the concave slope, unless other circumstances interfered. This is also to afford a better view to the engineman. In cuttings, the southern slope, by being made flatter, better admits the sun to the road-bed. Deep cuttings are made generally with flatter slopes than those of banks of the same height. This is to admit the sun and air, because the slopes of cuttings are less solidified than those of banks, and because the wash from cuttings gives more trouble in the ditches. On the other hand, embankments, although made of the best material, are sometimes based on a failing foundation. This subsiding, the ground would be forced upwards on one or both sides of the bank. Instead of adding fresh material from the top, which would probably aggravate the difficulty, besides being itself likely to slip off, a terrace of earth is sometimes built out over the swell, which is thus confined by pressure. The Hanwell embankment of the Great Western line once broke through the covering of a clay stratum beneath. The

swollen ground, as forced up on one side of the embankment, extended for 400 feet, with a width of 80 feet, a height of nearly 10 feet, and had been removed horizontally, by the sinking of the bank, for about 15 feet. Had this embankment been made originally with flatter slopes (its height was 54 feet), the extension of base, by distributing the weight over a greater area, would have saved the failure. As it was, this extensive work actually absorbed more material in its repair than in its original construction.

The face of a slope is strongest when curved so as to be flattest at the base, where the pressure is greatest. This approaches the analogy of nature, and is approximated in all earthwork, by the effects of time in gradually settling and washing down the slopes. This form is occasionally given in English railway earthwork. In districts where stone is abundant, embankments and excavations have been extensively faced with that material. There is no considerable saving of earthwork by facing embankments in that manner, although the retaining walls in cuttings do save a large quantity of excavation. High retaining walls, however, are not always permanent, unless made so by expensive supports, as by inverted arches at bottom, or by cross braces over the track.

Time is an unerring test of the slopes of railway earthworks. Whereas, in ordinary canal or roadwork, slips seldom occur after a year or two from the first opening, railway earthwork, unless correctly sloped at first, is liable to slips for many years, or until the slopes become sufficiently flattened. This has been the experience in England, and hence isolated cases of steep slopes of the earthworks of a few English railways should not be forced to stand as sufficient precedents for steep slopes.*

* *The Baltimore* and Ohio Railway, which is doubtless well sloped, *as American roads go,* is charged for 1857 with $34,293 for "watching

The vibration caused by the passage of fast trains is considerable, and has a disturbing effect on earthwork. It has been detected, in England, in some cases at 1½ mile from the railway. Near the astronomical observatories, the disturbance has sensibly affected the instruments, at the distance of one mile from the passing train. The blows of a pile engine, in driving piles in some kinds of ground, are sufficient to unsettle the foundations of contiguous buildings. This was the case at Lincoln, on the Great Northern line, where the station was supported by iron screw-piles in order to avoid this danger. This vibration must be an important cause of the failure of earthworks, so many years after the opening of a line of railway. In canal work, even, slips have been know to occur from the vibration caused by the sudden and careless closing of the lock-gates, the earthwork being of course already in a condition to slip easily upon any disturbance.

While the slopes are flatter on English lines, they are also protected by grassing, and are better drained than is usual in America; thus doubly increasing the durability of the former. In forming embankments, the turfs, occupying the intended base of the work, are removed to a depth of six inches, and placed aside for sodding down the slopes of the work when finished. So in excavating cuttings, the turfs, for a depth of 12 inches, are similarly reserved and applied. Where the turf is not available or suitable, the slopes are sown with mixed rye-grass seed and clover.

The slopes of many of the cuttings of English railways are extensively cultivated by the employees in the raising

cuts," while for surfacing, ditching, and removing and repairing slips, no less than $55,203 were expended—the whole expenses of maintenance and repairs of road being $581,979. The amount for watching cuts, and for ditching and repairing the effects of wash and slips, was over $235 per mile, or one-half as much as the entire cost of "maintenance of way" *on some* English lines.

of vegetables; the privilege being let out by the companies at a fixed yearly rent. It has been recently proposed to introduce the vine upon railway slopes having a Southern or Eastern exposure*—the inclination and character of the soil being peculiarly favourable to its growth. This plan certainly deserves a thorough trial in the wine-growing regions of the South-western United States. Cultivation binds the surface of the slope, promoting drainage and preventing washing, slips, and the discharge of dust. The protection of slopes by grassing requires that they be flat, as grass will not thrive on the ordinary steep slopes of American lines. The slopes of clay embankments have, in some cases, been burned to prevent slips.

In what has been said of slopes, their inclination has not been referred to the "angle of repose" of the material, as experience shows how many circumstances exist to render this insufficient.

Retaining Works in Cuttings.—Retaining walls have been sometimes adopted to save excavation. They have been generally calculated to resist the pressure of the earth behind them, estimating that pressure, according to Prony's law, as equal to the weight of a prism of earth slipping upon the face of the natural slope due to the character of the soil. But when the soil, by the collection of water behind the wall, becomes saturated, the pressure becomes due to the weight of the column of semi-fluid resting against the wall. Thus several instances have occurred where retaining walls, of great thickness and strength, have been moved bodily forward by the pressure of water at their backs. It has been necessary in some cases to brace these walls apart by heavy iron beams over the track, and at a height sufficient to clear the engines. It was at one time proposed, and the

* In America.

plan has been partially adopted in a few cases, to build buttresses opposite each other, and at intervals along the opposite faces of a perpendicular cutting. These buttresses were braced, each pair apart, by a reversed arch below the track and by a brick beam overhead—the beam being arched both on its upper and under sides. The intermediate faces of the cutting were supported by concave retaining walls abutting against the sides of the buttresses.

Formation of Earthwork.—European engineers insist on a thorough construction of embankments, in which are generally included the following conditions:

The surface intended to be covered by banks is shaved clean of turf; not only to remove it for sodding the slopes but to obtain a fair bottom, free from vegetable matter, on which to start the work. All stones, stumps, brush, or other obstructions, which, by their disturbance of the integrity of the bank, or by their decay, might cause sinking or slips, are thoroughly cleared. The culverts being in, are allowed ample time for the cement to set (most culverts on English lines are laid in cement) before the filling commences.

Banks of very bad soils, like clay or loam, are sometimes raised in lifts or layers of 3 or 4 feet each—each layer being well rammed or settled, so as to be concave on top. This is an expensive mode. The best plan for the least cost is to carry out the bank in two parallel rows or ridges, forming together the full intended width, and to fill in the intermediate space by subsequent tipping. This, too, is largely practised for bad soil.

Correct allowance is made for the settling of the material of the bank, and time is given for this settling to occur before the ballast is brought on, or the rails and sleepers laid. The shrinkage of earthwork sometimes disturbs the

grade at a rate of several feet rise or fall per mile; in nominal grades of 60 feet, on the New York and Erie road, a distance of 500 feet was found to rise at the rate of 75·4 feet per mile, this distance being approached and succeeded by the regular grade of 60 feet. In another place, for the distance of 200 feet, the rise was found to be at the rate of 116·7 per mile, with a level of 100 feet length, both above and below—the average grade over the whole mile being 60 feet. These cases are similar to what occurs where railway earthwork is not properly settled before being brought into use. The shrinkage of earthwork is stated to be as the cube of the depth; hence the necessity of due provision in lofty banks.

The embankments are generally carried out, at first, to the full intended width, and not exposed to slips by the subsequent addition of loose material, which does not unite with the original slope. Where additions become necessary for other tracks, the side of the bank is stepped, to give a hold for the material added.

Where level crossings are employed, it is usual to pave between the lines of rails, and to some distance on either side, to prevent the sinking of the track, abrasion of the iron, and straining of the fastenings, from the passage of heavy waggons. A still more important reason, is that the crossing is thus kept comparatively *clean*.

In *all* cases, during the formation of embankments, the greatest care is taken to exclude *water*, until the surfaces are finished, and the drains completed for the protection of the work.

Drainage.—To no details of the road-bed is more attenion paid, by English and French engineers, than to those necessary for the removal of water. This is the great de-

stroying element in all earthy structures. "The history of all failures of earthworks shows the disasters consequent upon inadequate drainage," and it may be added, a large part of the continual heavy expense of maintenance of our lines can be traced directly to the same source.

The action and effects of water, although daily exhibited, may be briefly recapitulated. Water, running on the surface, dissolves and washes the earth, soaking the road-bed and choking the ditches. When soaked, the road-bed loses its firmness and the ballast sinks irregularly. This displaces the track, thus increasing the resistance and adding greatly to the wear and tear of both track and machinery. Where the ballast sinks, many of the sleepers will be left clear and hanging by the rails. These, on the passage of a train, deflect deeply, thus opposing a heavy grade against the wheels. This is proved by the oozing of mud from under the ends of the sleepers in wet weather, and the dissipation of clouds of dust in dry seasons.

Water, standing in contiguity to earthwork, is equally injurious. No matter what may be the height of an embankment of loam, sand, or clay, water, if in reach of it, will rise to the top, being carried by absorption, and will produce all the effects just stated. Water not only destroys the cohesion of the material of the road-bed, but swells its bulk. It is sure to displace the best laid track.

In cuttings, water will thus convert the whole road-bed into mud. Whenever this dries in the sun it is partly dissipated in dust, while clayey soils will shrink and crack in every direction. The slopes, already worn into gullies by the action of running water, will also fill with dust.

On the other hand, frost setting in just after a heavy rain, or while the road-bed is otherwise soaked from stand

ing water, will heave the track irregularly and hold it there, as rigid as rock. No condition can be worse. When, in the following spring, the frost is coming out of the ground, and the road-bed is washed by the thaws from adjacent lands, the earthwork reaches its complete stage of saturation. Stratified soils will thus slip, if ever.

In an economical view, the damage occasioned by water is far greater than the utmost cost of its removal. It does not need extreme conditions to produce the effects stated. Partial saturation, occasional washing of banks and moderate rigidity in winter, are all sufficient to disturb the track, although perhaps not to an inconvenient extent, and in such case the iron is more or less bruised, the fastenings strained, the chairs broken, the ties rotted, the resistance, and thereby the consumption of fuel increased, and the whole wear and tear greatly enhanced. An able authority says,* "Wherever water is known or suspected to exist, its immediate source should be traced and *every possible means* adopted for diverting it from the slopes and adjacent surfaces."

Thorough drainage must provide for the immediate removal of falling water from the surfaces of the earthwork, it must cut off the communication of water from the tops of slopes and at a point at least three feet below the rails, and it must reduce the force and conduct away the discharge of descending currents on slopes. Drainage may, therefore, be considered under three heads: that of the road-bed, that of slopes, and the local surface drainage by ballast, which will be considered under the head of ballast.

Drainage of Road-bed.—The side drains, on English lines, vary in width from 3 to 13 feet, according to the ground and the quantity of water to be passed, and are from 3 to 6 feet deep below the level of the rails. These dimen-

* The late Robert Stephenson.

sions are wholly dependent on circumstances, but these circumstances are carefully regarded in most cases.

The formation level, as has been seen, is made sufficiently wide to give a good interval between the rail and the ditch—a level space being left between the bottom of the ballast and the edge of the ditch, on which any wash, carried from the road-bed, may rest without choking the drainage. A similar space is usually left outside of the ditch in cuttings. Much attention is paid to cutting the ditches straight, and at an equal distance from the track at all points in their length, so that whatever the road-bed may expand from water, the swelling shall be at least as equal as may be at all points. The inclination of the ditch is carefully attended to, so that they shall not serve as reservoirs for stagnant water — the nearest outlets being sought into every neighbouring watercourse of sufficient extent and activity to support the required discharge.

The culverts are located and their capacity determined upon the same considerations. As works of construction, they are generally of the most permanent character, built of brick or stone, laid in cement, and well settled before being covered in. No excellence of ballast can keep a road-bed dry except the surface is fully three feet above the reach of water.*

As every engineer knows, the portions of a track laid along low embankments are usually better than those in cuttings. In the latter where the drainage is likely to

* One American line in particular, the Boston and Lowell, once furnished the best evidence of this. The second track was laid as follows: —A uniform trench 11 feet in width and 3 feet deep, was excavated and filled with clean gravel, the sleepers being bedded in this as ballast; this track heaved badly, and was only made smooth by subsequently opening out ditches four feet below the rails, cutting off the water; this track was afterwards the best part of the road.

be imperfect, the wear of rails and general disturbance of track, on roads in America, is found to be from one-fourth to one-half greater than on other portions; yet the drainage is the only circumstance which can affect this result.

In ordinarily level ground, the road-beds of English lines are raised so as to be well above the reach of water. In cuttings the track has more or less slope towards each end, both to reduce the quantity of excavation, and to keep the side ditches clear. Where, in cuttings, the grade rises steeply, the side ditches are generally lined with stone, both to save excavation and to prevent the ditch from washing. Such a ditch would be, say 33 inches deep, 18 inches open at the top, paved with 3-inch flagging stone at the bottom, and laid up with walls of 12 to 15 inches thickness.

On the London and North Western line, cross underground drains of circular and perforated tiles are used to a considerable extent, placed well below the ballast. In some of the deep chalk cuttings, the side drains are of large bricks running the whole length of cutting underground, with cesspools or eyes, at convenient distances, to take off the surface water. Semicircular half-brick open drains are used for the sides of some of the cuttings. The underground drains are sometimes made of semicircular bricks, perforated and based on 12-inch square paving tiles as a bottom. In very wet cuttings, and in tunnels, covered drains are made under the middle of the road-bed. Some are oval, three feet in vertical diameter, and two feet wide, the bottom being from four to five feet below the surface of the ballast.

The experience with sub-drainage, whether adopted in cuttings, or for clearing the slopes of railway earthworks,

or for rendering farm lands cultivable, has proved favourable. A covered drain will draw more water than an open ditch of ten times the capacity. Sub-drainage is, doubtless, both cheaper and more efficient than the system of open ditches, and its occasional and successful adoption on certain English lines, should lead to its further introduction here. The drains should be sunk at least three feet below the surface, and pains should be taken to keep them clear. In many cases, marshes may be drained merely by tapping them below. With some geological knowledge of the formation of the valley or basin, it will often be found that an impervious substratum underlies the marsh, thereby containing the water as in a bowl. Where such is the case, and the porous strata beneath are not charged with water, that from the marsh above may be let into them by tapping through at the lowest places. In this way, marshy districts especially if at any considerable elevation above the sea, or above any of the great natural reservoirs of water, may be cheaply and effectually drained.

Drainage of Slopes.—At the top of cuttings through ground which is level in transverse section, ditches are made on both sides, to prevent the surface water of the adjacent fields from washing down the slopes. These ditches are generally set well back from the edge of the cutting, so that the water shall not break through and cause slips. In cuttings in sideling ground, the top ditch is made on the upper side only. These crest ditches are carried out and have their outfall at the ends of the cuttings. The bottom ditches have only to receive the drainage of the slopes. The surface of the slope may be intersected by numerous shallow open drains (spade drains as they are called), running either straight down from the top to the bottom, or diagonally each way, so as to form a continual

outline like W W on the face of the work. In studying surface drainage on the grand scale of nature, we never find flat slopes. In steep ground the watercourses are small and numerous, furrowing the surface at irregular distances in various directions. So in artificial ground, the analogy must be preserved, or else nature will enforce the discharge denied or obstructed by art, or in practical terms will wash gullies in the slopes. "Benches" on the faces of slopes are occasionally used to collect the water and wash from above, and retaining the latter, to let off the former with diminished force into the bottom ditches. Their principal use is in stratified ground, where they may follow the line of separation between two strata, the upper one of which may be liable to slip. It is believed that benches, however, by giving opportunities for the lodgment of water, often cause slips, and hence they are not very often employed in other railway earthwork.

The slopes of embankments require occasional surface or spade drains for the descent of rain water, or that coming from thaws. They are generally provided also, on other railways with bottom drains. These not only prevent the base of the bank from being torn away by the water, but they prevent also the soaking of the bank by the standing water which might otherwise collect around it. The same shelf is left between the base of the bank and the ditch, as is left for the protection of other ditches.

In embankments in sideling ground, where the bank serves as a dam for all the water from the rising ground above, instances can be pointed out on some American roads of culverts being opened through at a considerable distance above the bottom of the original drainage way. The water, thus confined, must either stand against the bank, or wash through on its old bed—thus washing out

the earth on the lower side of the embankment as well as loosening it on the upper, and at the same time saturating the whole. Wherever earthwork is soaked with water, the ballast and sleepers sink, throwing the track out of line and adding enormously to the resistance and wear and tear.

In the deep cuttings of English railways—often through clay soils—the thorough drainage of the slopes is a matter of the greatest consequence, as the ground is not only likely to slip, but the ditches would otherwise choke, and the road-bed be turned into mud. The soils intersected include those of the worst description as regards drainage—peat, clay, mud, &c. In many cases, the soils being stratified with seams of clay, shale, sand, and shells, often of considerable dip, the tendency to slip is very great. In all cuttings in stratified soils, there is a continual agency at work to produce slips in this way. The soil when saturated with water, swells, and can only move laterally towards the unresisting opening of the cutting. Drying again, this ground cracks; the fissures rapidly fill with dust or sand washed or blown in, another saturation thus produces another swell, with a further movement, until a fall or slip occurs. When the ground is usually full of water, certain clays or marl will become so soapy or greasy, as almost to destroy the friction between the strata, which, in inclined seams, is all that holds the upper soils in place. In some, the soil may so far dissolve as to run over in a semi-fluid state, thus undermining solid earth above. All these cases occur in different situations: the only security is to slope amply, and to thoroughly intersect the springs and water bearing seams or strata, by means of drains.

The most prominent plans for draining the slopes of cuttings are, 1st, underground perforated earthen pipes of say 3-inch bore, the perforations being larger within than

without; 2nd, gravel or other porous counterforts in the face of the slope; and 3rd, dry wells or shafts, sunk perpendicularly in the slopes, and drained by underground pipes.

Conclusion as to Earthwork and Drainage.—In the construction of European and American railways, there is more difference in respect of earthwork and drainage, than in any other particular. Observation and science alike show that in our earthwork (including its drainage), more than in any other single detail of our construction, are American railways deficient. It is the weak point of the system. Whoever is anxious to discover the reason why the average cost of maintenance of these lines are, in some cases, 150 per cent. greater for the same mileage, than that of the railways of England, may search hopefully for it in the condition of such road-beds. No engineer will deny it.

To the solidity and thorough drainage of the earthwork of English railways must be attributed a large part of their economy of maintenance, and much of the economy of fuel with which they are run. The support being FIRM, and the fastenings ample, the track remains smooth and the trains run quietly. American railways experience the opposite effects of insufficient earthworks and imperfect drainage, whereby the road-bed sinks unequally, the sleepers lose their full bearing, the track is displaced, the fastenings strained, the rails subjected to excessive wear, while all the shocks react on the machinery, largely increasing both its wear and tear, and the consumption of fuel. And we have ample evidence that iron and sleepers have twice the life in British railways that they attain in America, that the repairs of road-bed are *far less, while* the consumption of fuel and repairs of rolling *stock, for their* mileage, are but about one-half the average *n the United* States.

Ballast.—*Materials.*—A great variety of materials are used as ballast on English railways. These are broken stone, burned clay, cinder, sand, shells, broken bricks, and culm, or small coal. The preference turns between broken stone and gravel, and where the latter has a natural mixture of clean sand, it is probably preferred in most cases.

The ballast has four distinct offices to perform. It must, first of all, distribute the bearing of the track over the surface of the earthwork; second, it must confine the track in place; third, it must secure the drainage of the surface, and lastly it must, by its character, give a certain elasticity to the road—uniformly intermediate between the rigidity of rock, or the hard bottoms of cuttings and the weakness and softness of common earth.

Very hard materials do not meet the last named condition of an elastic absorbent. Broken trap rock, however durable in itself, would pack to such an extent as to approximate the condition of a solid ledge, on which the rails would soon batter out.* The packing of even gravel ballast has been often such as to cause a rapid destruction of the rails. Stone, when broken for ballast, should not exceed 2½ inches in any diameter. Limestone rock is quite durable, but it is of so binding a character as to pack too readily when used as ballast. Gneiss rock, although not sufficiently hard for common road covering, answers very well for ballast, and breaks easily. On the Eastern Counties railway, broken sandstone, although soft, is preferred as affording an easy road. Slate rock is the poorest kind of stone ballast, being rapidly decomposed in wet weather.

* On one part of the Manchester and Leeds line, the bottom of a rock cutting was dressed to a surface, and the rails spiked directly to it. A few weeks' experience was sufficient to cause the rails to be taken up and to be re-laid in the usual manner.

Hard stone ballast should never be used in cuttings. Gravel, if too fine will not drain well; if too coarse it will not pack sufficiently to prevent the sleepers from sinking into it. It must be carefully selected, also, as to its quality. If from the sea-shore, it will hardly bind at all; if mixed with loam it will never drain well. If it has a natural mixture of clean sand, it will be of the best quality.

Burned clay is a tolerable substitute for other ballast, where clay only can be found. It has been considerably used on English railways, and may be adopted on many lines where neither stone nor gravel can be had. Coal, of a quality fit at least for burning clay, can be found at so many points in the prairie (U.S.) countries, that it may prove quite convenient and otherwise advantageous to adopt burned clay very generally for ballasting prairie roads. In burning clay a wood fire is first lighted, on which is placed a quantity of bituminous coal, and when this is well ignited, the clay is placed around and upon it in a moderately thin layer. Coal and clay are then applied alternately —the clay in lumps, and never so thickly as to choke the fire. In this way, a bank or kiln of clay, up to any size, may be made up and burned. On the Great Northern, these banks were laid up about 200 feet long, 60 feet wide, and 20 feet high. The clay finally becoming burned, although more or less irregularly, it is broken up and carried away. Much depends on the care exercised in burning. In some portions of the bank the clay will be vitrified (which makes the best part of the ballast, excepting that it requires too much coal in burning), while at other places the clay may be underburned, and, in this case, liable to dissolve in wet weather. A ton of coal should burn from 20 to 25 yards of clay, and in the case of the Great Northern line, with coal at 16*s*. a ton, the ballast was got

out at 1*s.* 3*d.* a yard—about as cheap as gravel can be got out and run 6 miles in America. Clay is sometimes burned over in a similar manner, where it forms the substance of embankments. The water once out, the baking of the surface excludes it from the interior, and clay, if kept thoroughly clear of water, is as good as any other material for embankments. Sand is only very rarely used as ballast on some railways. It hardly deserves the name of ballast. It is not firm under pressure; it will not drain well; it rapidly washes out, and by being blown up by the trains in motion, it gets into the bearings of the machinery and does great mischief. It cannot be depended on for a smooth track, least of all in winter. Cinders, shells, and broken bricks all serve a very good purpose where they can be had. The two last are extensively used in ballasting railways in Holland. Small coal, mine rubbish, and culm, or coal incompletely formed, are all excellent for ballast. There are many places where this material can be had without too great cost; and in such cases it should never be neglected. It forms a firm yet elastic ballast, and drains very well.

Quantities.—The English double-track roads of common gauge have a general width of 36 feet of ballast. Single track roads are ballasted 14 feet. This wide ballast-bearing is obtained by means of the ample width of earthwork already noted. Where there is any variation from these standards, the ballast is *wider,* seldom narrower. The South Eastern main line was ballasted 30 feet wide, the width of formation level being 36 feet. The standard French width is 27 feet $6\frac{3}{4}$ inches—or 8·40 mètres.

The depth on English lines is generally 2 feet, 1 foot of which is entirely under the sleeper—the rest around and above it. Some lines have been ballasted 28 inches deep. It is generally intended to employ from 10,000 to 12,000

cubic yards of ballast per mile of double track, and not less than 6000 yards for single tracks of ordinary gauge. By these quantities are to be understood the original amount of ballasting, without regard to what may have been filled in where the track has sunk. In one case, on the Great Northern line, 26 feet depth of ballast has been filled in on a single bank. In other cases, 2000 yards of ballast have been often added in one year to the original quantity on one mile of road, the track being settled by the saturation or washing out of the earthwork. The French lines have generally 20 inches (nearly 50 centimètres) of ballast, except in bad soils, where 23½ inches (60 c.) are applied.

European engineers attach the greatest importance to the use of ballast, and the comparison of the cost of keeping up roads both with and without ballast, shows how important it is, not only that it should be used at all, but in the best manner, and of the best quality.*

Laying Ballast.—The primary object of ballast is to distribute the weight of the track, and applied load over the surface of the earthwork beneath; hence in ballasting this object should be kept especially in view. The earthwork is in no case fitted to sustain any load until it is thoroughly drained. It is usual also to slope the surface of the "formation level" each way from the centre, the outer edges being three or four inches lower than the middle. This is not perhaps very important—at all events the inevitable settling of the ballast will in a short time obliterate the line of separation, after which it will never be restored.

English engineers usually lay twelve inches of ballast

* The French double track roads, as by the *Annuaire Officiel des Chemins de Fer*, for 1857, have expended no less than $6039 per mile for ballast, or 17 per cent. of the whole cost of "way." (115,000 francs per kilomètre.) This would give 10,000 yards per mile, at 2s. 4d. per yard.

before the permanent track is put down, the contractc using his own temporary rails in building the road. Th ballast thus deposited is as well solidified as circumstance will allow, after which the sleepers are laid in place and further quantity applied. Much pains are taken in beddin the sleepers firmly, and at their proper level, and prope distances apart. With broken stone, the largest pieces, s far as they can be kept separated, may be placed at th bottom. These pieces will so wedge into each other a not to be likely to come up to the surface; but where, wit gravel, the coarser portions are laid at the bottom, th action of frost, and the working of the road-bed under pass ing trains, will bring them up again to the surface, an while this is going on, the track will be more or less dis turbed. Flat stones have been laid under the ballast; i cases where they have been placed in the same manne under the broken stone covering of McAdam roads, the have become in time turned upon their edges, thus keepin the road continually rough; but the action is different i the case of a railway, since the bearing of the sleepers more distributed than that of waggon wheels.

Ballasting, after a road is in established use, is to a grea extent, inconvenient and expensive. It is very difficu to remove the poor material from under the sleepers, whil if not removed, it is not a fit foundation to ballast upo Besides, alongside stations and under bridges, there is no always room sufficient to allow of raising the track by th necessary thickness of the ballast. The ballasting shoul in all cases be finished as soon as possible after the openin of the road, as it would be expecting too much at preser that our roads should be ballasted *before* being opened f use, as is always done abroad.

The greater width of ballast permits the use of

sleepers than are now put down on roads in the United States. Nine feet is the common length abroad, thus distributing the load more uniformly upon a wider base. So, too, the filling in between, and at the ends, and over the sleepers, holds them much better in place.

In prairie soils, where the deep loam is unable to support the direct weight of the track and its load, a permanently smooth, strong railway can only be made by ample ballasting. It was by obtaining sufficient *bearing* that Stephenson floated his railway over Chat Moss; and by as much as a prairie differs from a rock bed and approaches the character of a peat bottom, by so much must the bearing of the track be distributed over the surface, else the sleepers will be forced irregularly into the ground and the rails more or less disturbed. The expediency of any ballasting for some of the Western lines (U.S.) has been doubted from the fact that the ballast, when laid in certain quantities, had been found to be forced into the ground. No mechanical reasoning, however, could be more illogical, for while a thin coating of ballast would be beaten into the ground, a greater thickness would distribute the weight over a surface from four to six times larger than that covered by the sleepers, and would thereby reduce the crushing force upon any given point. Each fragment of rock or pebble of gravel, when upon the top of the ballast, exerts pressure throughout a cone of similar fragments or pebbles until the final bearing of several square feet is reached on the bottom. Thus the cap ball in a pyramid of cannon shot presses upon all those below it, its weight being finally distributed over an area perhaps five hundred times greater than that of its own section. If the soil is not originally fit to receive ballast, it must be drained, for the *road will be still* worse if it is laid on such soil without *ballast.*

The support given by ballast must be intermediate between rigidity and weakness, for either extreme is equally injurious. Firmness without rigidity is the great requisite. Much slovenly work is tolerated in railway road-beds by confounding weakness with elasticity. This will be again referred to farther on.

Draining by Ballast.—Broken stone, in fragments of from 1 to 8 inches diameter, has been found to give room in its interstices for an amount of water equal to 48 per cent. of its gross bulk. Even anthracite coal, which is specifically much heavier than water, will weigh when broken into ordinary market sizes, some seven pounds less per cubic foot (or 12 per cent. less) than water. Gravel will not contain as much water as broken stone, except by the dissolution of its contained earth.

In ballasting a railway, the material used will drain water at a certain angle out to the edges. Although the surface is not waterproof, the water will not settle perpendicularly into the ballast if sufficient means are left for it to escape at the sides; hence walling the ballast at the side, or enclosing it in a trench in the ground, only causes the water to saturate it throughout. The water must have opportunity to drain from, as well as into the ballast. A case already mentioned, that of the Boston and Lowell road, where the ballast occupied a trench 11 feet wide and 3 feet deep, and was always saturated and heaving in wet weather, shows the necessity of keeping the drainage clear even with ample ballast. If the ballast is allowed to remain saturated with water, this will also, by increasing the grinding power of the stones, wear them out under the motion imparted by passing trains.

Over drains, the finest ballast—sand—will pass wate *freely*. *By* removing the water, ballast assists in extendi

the life of the sleepers, which would otherwise be prematurely rotted. Many of the Western (U.S.) mud roads have been surface-drained, in default of ballast or money to buy it, by crowning and smoothing the mud between the rails, and sloping it to ditches at the sides. This reduces the firm bearing of the ends of the sleepers, and allows the track to rock considerably. But it is, on the whole, better than letting the superstructure lie in a puddle of water.

Cost of Ballast.—The operations on the New York and Erie road, in 1852, showed the cost of ballast to be 25·7 cents per cubic yard. The average distance run for each train, loaded and empty, including also the distance run in going to the work in the morning and returning in the evening, was 5·4 miles. The average haul of the material only was not far from 2½ miles. The greater portion of this work being widening the "cuts" and enlarging the ditches, the earth trains were subject to much greater detentions by other trains than would occur in loading ballast on side tracks. The number of cars in a train was much smaller than would be used in ballasting. Broken stone ballast, as laid on the Baltimore and Ohio road, has cost about 40 cents. a yard. The stone ballast on the Pennsylvania railway is charged at 65 cents, equal to $3,250 per mile, at 5000 yards per mile of single track.

In carrying gravel or other ballast, in long runs of from 10 to 50 miles, the cost of transportation should not exceed ¾ per cent. per yard per mile. A train of 200 yards should be run 40 miles daily, returning empty, at a cost of $50 for running expenses and dumping, the ballast being already loaded in the cars.

Conclusion as to Ballast.—The best railways in the world —*those which do* the most business at the least cost—are *the best ballasted.* The French double-track roads have

averaged over £1200 per mile for ballasting, and are maintained under their current traffic for £400 less per mile annually than the cost for the same mileage in U.S. This ballast once on, will not lose more than one or two inches a year. As ballast best fulfils its purpose when it is provided of good quality and in sufficient quantity, it may be concluded that two feet depth of clean (not too clean) gravel, of broken gneiss rock, or carboniferous limestone, or even well-burned clay, will secure all the following conditions:

First, distribution of the bearing of the applied load. Where the bearing surface of the sleepers only is from two to two and one-half square feet per foot of track forward, two feet depth and fourteen feet width of ballast will extend this bearing to fourteen square feet upon the surface of the earthwork. This prevents the crushing of the road-bed.

Second, by enclosing the sleepers on all sides, the track is held steadily in place, and the trains run quietly. No mere depth of ballast, where it is all beneath the sleepers, can accomplish this. The sleepers are also greatly protected from decay when thus enclosed.

Third, drainage is secured, the surface water running through to the edges. No depth nor excellence of ballast however, can compensate for insufficient drainage of the earthwork. The ballast is not waterproof itself, while if the ditches are not well opened, the road-bed beneath will be constantly saturated by absorption of water from the slopes.

Fourth, with the usual materials, say those named above, a certain elasticity is interposed between the track and the earth-bed. This is always desirable, and although ordinary soil will yield in a similar manner, its conditions cannot b[illegible] *depended on*; it is at one time dissolved in mud or sc[illegible] *tered in dust*, or else frozen to nearly the hardness of r[illegible] *Broken stone* is a good covering for banks, but i[illegible]

bottoms of cuttings it is too rigid, and a more yielding ballast should be adopted.

Fifth, ballast to be good, must be *clean*. Sand or natural soil, by rising, does great injury to the machinery, and by its presence on the tread of the rail greatly increases the resistance there, as well as in the bearings, adding to the consumption of fuel and oil, and to the injury to the paint and upholstery of the carriages, and being an intolerable nuisance to passengers.

ELASTICITY OF PERMANENT WAY.—Extreme deflection and looseness of rail-joints *versus* anvil-like rigidity of joint-fastenings, has been the basis of permanent way discussion in America ever since improvement began. That such a controversy has been mostly confined there, is a fact which throws some light on the case; where smooth roads are the rule, the consequences of rigidity are not so noticeable; where frost-heaved and hardened roads prevail, rigidity is most destructive of way and equipment; and this is the essence of the whole matter.

Elasticity is a compromise between smoothness and hardness. Were roads *perfectly* smooth, elasticity would be not only unnecessary, since there would be no shocks nor jars for it to relieve, but it would be positively injurious, since it would disturb the perfect level. On the other hand, where roads are most rough, there are most shocks and concussions, and the greatest amount of elasticity is required to counteract them — to enable the wheels to force the track into a more nearly level line than would be possible if it were absolutely unyielding. Since no roads can be made, much less kept, perfectly level, elasticity in the track, *just in proportion to the roughness*, is an indispensable element of economical traction and repairs. We hear

numerous dissertations on elasticity; almost every inventor of a rail-joint may be better identified as an inventor of a new theory of elasticity designed to meet his case. The inventors of "anvil" joint-sleepers, insist that immoveable stiffness and firmness will alone preserve the *level* of adjacent rail-ends; this would be true if tracks were laid perfectly smooth; the advocates of *springs* (and there are such) under the contiguous rail-ends, declare that the sensitive and palpable *give* of the whole mass will alone prevent the lamination and destruction of the bars; this is true if mud tracks are allowed to sink here and heave there, and finally freeze up into a succession of adamantine hillocks.

It is unreasonable to assume that elasticity of track is any more a fixed quantity than fuel or water. They all vary with the resistance. Elastic tracks, and especially elastic fixtures at the break in the rails, where most jar and shock occurs, if continuity of line and perfect level are not preserved are of course indispensable to our roads, when they freeze up, or are, from any cause, rough and rigid. As far as all parts of the track, except the joint, are concerned, the wood sleeper, or an iron sleeper on a good thickness of ballast, although they do not spring *perceptibly*, are sufficiently elastic to absorb all the jars and concussions occurring on a well-kept line. This is a matter of history, and we believe it will not be questioned.

The breaks in the rail, however, are differently circumstanced. There are three principal cases to be considered. First. Suppose the road-bed to be bad—without ordinarily good ballast and drainage, and the rails to be without joints. The mud road-bed is already too yielding if it were only perennial mud; but where the fantastic surface of a clay and water road is suddenly caught by the frost, elastic material in chairs and sleepers is suddenly called upon for most essential service. Even while the super-

structure is wallowing in the mire of spring thaws and freshets, the elastic material is of some service, for where wheel, rail, and all drop down to the bottom of a puddle, they need a cushion to arrest the blow.

Second. Supposing the road-bed to be good, fairly ballasted, and drained; if the breaks are not so jointed as to preserve continuity of level and stiffness, the concussions are greater than at any other parts of the rail, and the elasticity of sleepers and ballast are not sufficient to prevent their rapid failure. Therefore, the mere addition of metal to or under the break decreases an already insufficient elasticity, and is therefore inadequate. On the other hand, the addition of elastic material under the break will partly remedy the defect—*partially*, because it will only relieve not prevent the severe forcing down of a rail end; an anvil joint would increase it: a simple light chair or sleeper would not much better it; but an elastic material under the rail would certainly *relieve* it. To stop here—to merely compromise a defect is a very low aim, and a very unwise one. One important feature is necessary to the utility of a joint in either of the above cases, viz.: where one rail-end is depressed, the adjacent end also should come down to the same level—the continuity of the rail should be preserved, however slightly the stiffness and strength may be provided for. Otherwise the elastic material, and the sleeper, and the road-bed, would yield under the weighted rail, and leave the other pointed straight at the wheel, from which it would receive a shivering blow. A sleeve chair, if the elastic medium were *in* the chair, would bring both rails down as the sleeper and road-bed settled, and a fish-piece, even were it a mere hinge or ring, would bring both rails to the same level, whatever might be the yield or elasticity.

Third. Since we cannot imagine a thorough joint, pre-

serving the stiffness, level, continuity, and strength of rails, in connection with a mud road—for whoever adheres to the latter will certainly never use the former—the next case to be considered is that of a thorough joint and a good road-bed. It would appear that the elasticity of the sleepers and ballast would be all that is required under such favourable circumstances; but this is not the case. On European roads, with the most thorough and excellent joints, allowing no more deflection than occurs at other parts of the rail, a decided and considerable lamination of the rail-ends sometimes occurs. This has been especially noticed in case of a very heavy cast-iron sleeper on the South Eastern line; the fish-joint meanwhile being of the most thorough character, and the deflection of the joint and of the rail generally not being visible, if it was measurable, the rail began to fail at the joint after very short service. This shows two things, 1st, that it is not necessarily a visible deflection, but a mere jar that does the mischief; 2nd, that the best joint alone on even a smoother track than we shall probably enjoy for many years, is not a complete guarantee against the destruction of rails and machinery; for which the reason is evident: there is more metal in a joint which is as stiff as the unbroken rail, than there is in the rail itself; and there is especially a greater mass of matter acting like the anvil, if the joint is made on a sleeper.

The practical fact growing out of all this, with reference to a *first class road*—and it is bad policy to spend much time in trying to compromise the evils of a bad one—is, that a thorough system of rail-joints requires more elasticity under the joint than under the less weighty and massive parts of the structure; that the interposition of a substance, not visibly springy, but slightly elastic, to relieve the greater rigidity of the mass, is necessary to economical traction and maintenance of way. If a road is so smooth

—that is to say, if ballast and drainage are so thorough, sleepers so ample and firm, rails so stiff and level, and joints so tight and strong, as to enable even a cast-iron sleeper to afford sufficient elasticity to the body of the rail—then a stratum of wood, rubber, cork, felt, or some more elastic material than a cast-iron sleeper, is necessary to give *the same* amount of elasticity to the joint; and if it does not have the same amount, it will begin to fail before the body of the rail, by reason of excessive rigidity if it has less, and by reason of excessive yield and deflection, if it has more.

The whole system of *superficial* road-bed contradicts every idea of *permanent* way. The foundations of a permanent building or bridge are placed at a depth which insures uniform resistance, hardness, and support at all seasons, and, convulsions of nature excepted, for numberless centuries; witness the tremendous weight of cathedral towers, of temples, and pillars, which have not settled in a thousand years as much as an ordinary rail-joint deflects at the passage of a train. On the other hand, a railway is entirely on top of the ground. Its superficial foundations are at the mercy of frost and thaw, of rain and sun, of cold and heat. Each meteorological change alters their resistance, hardness and support. In the climate of the United States, only two things can prevent the change from summer to winter, from practically destroying the permanence of way. The first is a perfect filter of ballast, so fine that it will not be rigid, so coarse that it will not hold water by capillary attraction, so wide that the changes by frost at its edges will not alter its level, so deep that frost cannot affect the earth under it, and so securely founded on a solid earthwork, that it will not settle or yield. The second is an absolutely water and frost proof covering over the foundation earthwork, which would effect

the same results. Both these conditions of permanence are practically impossible, but suppose they were had, how long would they last? The very jar of the superstructure would gradually wear out the ballast and prevent its proposed protection, or it would necessitate the breaking of the waterproof covering. Of course, the thorough ballast and drainage plan would make an almost perfect road, and would much reduce the expenses of traction and maintenance. But it would *cost* almost, if not quite as much, as a really *permanent* way.

Now suppose we were to locate our superstructure on such foundations as we would build for bridges and cathedrals—not as to dimensions and amount of resistance or support, for that is not required, but as to permanence; suppose in localities where ground is soft and timber not too expensive, we were to lay our rails on piles, driven far below the influence of frost and water, where they would remain for say 100 years without yielding a hair's-breadth; or suppose where stone is more convenient, and the bottom adapted to it, the superstructure were laid upon suitable piers, similarly founded. It is not our purpose to elaborate an idea so foreign to all railway practice, especially in a country where still farther cheapening the permanent way by robbing it of its necessary proportions is the rule. But we believe such a system will one day be adopted. One popular objection to it may be referred to under the present head, viz.: elasticity. We shall be reminded that a superstructure laid on a solid stone bottom in England, very soon failed from excessive rigidity. What of it? Must elasticity be forbidden and excluded because the *foundations* are permanent? Are the two conditions in any way opposed or incompatible? If it is true that a certain and the same amount of elasticity are a necessary condition of a tra

which is not infinitely level—and we think this may be set down as a self-evident fact—then the attainment of this uniform level through the means of a medium of *constantly varying elasticity,* viz., a superficial road-bed, is simply impossible. If we decide to have a uniformly elastic track, we may rest assured that we shall never derive the required quality from the road-bed, but only from a uniformly elastic medium, interposed between a perfectly rigid foundation, and the rail. Therefore, perfect rigidity of foundation is not only unobjectionable, but it is a positive condition of a smooth and permanent way.

CHAPTER II.

SLEEPERS.

MATERIALS AND ARRANGEMENT.—The usual plan of the superstructure of European as that of American railways, is upon transverse wooden sleepers. The Great Western railway, and a few short lines, remain upon the old plan of longitudinal bearings. Cast-iron is now receiving considerable attention as a material for sleepers, or bearing plates. The castings are detached plates, resting on the ballast and supporting the rails, wrought-iron tie-rods being employed at every six or eight feet to keep the track in gauge. Stone blocks have been almost entirely discarded—a reference to what has been said under the head of ballast, will disclose the principal reason, that of their rigidity. So far as permanence and durability are concerned, they are superior to timber. Three or four plans of rails--as will be described under their appropriate head—have been adopted to some extent to dispense with or modify the use of sleepers, the

rails being of a form and size to take a continuous bearing directly within the ballast. The sandwich rail, a deep girder with longitudinal side-sleepers, is perhaps the best plan in use. The experiment of spiking the ordinary rails directly to the dressed bottom of a rock cutting, to dispense with sleepers, has been already referred to.

Quality of Timber.—Timber for sleepers should be certainly as sound and well seasoned as for any purpose. In actual strain and abrasion and in the effects of weather, a railway sleeper is severely tried. Seasoned white oak is of course the best where it can be had. On curves, it should always be put down if it can be procured. Professor Johnson's experiments show that thoroughly seasoned white oak holds a spike with twice, and thoroughly seasoned locust with 2¾ times the force of unseasoned chestnut. He found that in the softer and more spongy kinds of wood, the fibres, instead of being forced back longitudinally and condensed upon themselves are, by driving a thick and especially a rather obtusely pointed spike, folded in masses backward and downward so as to leave, in certain parts, the faces of the grain of the timber in contact with the surface of the metal. Also, "that the absolute retaining power of unseasoned chestnut on square or flat spikes of from two to four inches in length, is a little more than 800 pounds for every square inch of their two faces which condense longitudinally the fibres of the timber. The experience on the Pennsylvania railway shows hemlock to be superior to chestnut sleepers. If it becomes usual to preserve sleepers by chemical means, white pine, elm, poplar, locust, cottonwood, &c., will be found to take up the solutions more readily than oak, hard pine, &c.

Sleepers should be got out straight as well as of large uniform sizes. A crooked sleeper gives a very poor bearing,

which is not infinitely level—and we think this may be set down as a self-evident fact—then the attainment of this uniform level through the means of a medium of *constantly varying elasticity,* viz., a superficial road-bed, is simply impossible. If we decide to have a uniformly elastic track, we may rest assured that we shall never derive the required quality from the road-bed, but only from a uniformly elastic medium, interposed between a perfectly rigid foundation, and the rail. Therefore, perfect rigidity of foundation is not only unobjectionable, but it is a positive condition of a smooth and permanent way.

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and often by its rolling tendency acts to disturb the track, even where the bearing is otherwise sufficient.

*Preserving Timber for Sleepers.**—The ordinary life of sleepers, laid down in their natural state, is about 7 years. In this condition they cost about one dollar each on English railways. This is $3,600 per mile of double-track, and the average annual decay is, therefore, $514 per mile. By chemical preservation, their cost, at $1 25 each, is $4,500 per mile; but as they are thereby rendered durable for 15 years, their average annual decay is but $300 per mile of double-track. This saving is so large that some mode of preservation is always adopted on foreign railways.

The preserving liquids severally employed are as follows:

Coal-oil, which is the common coal tar of the gas works, with its ammonical liquor expelled by boiling. The process is called Creosoting.

Solution of sulphate of copper (blue vitriol) in water, in the proportion of 1 pound of the salt to 12½ gallons of water. This is Boucherie's process.

Solution of bi-chloride of mercury (corrosive sublimate), 1 lb. to 15 gals. of water. The process is called Kyanising after the inventor, Dr. Kyan.

Solution of chloride of zinc, 1 pound to 8½ gallons of water, or 1½ to 100 by weight. This is Burnett's process —Burnettising.

Solution of sulphate of iron (green vitriol or copperas). This preservative is prepared in a strong solution which, after being forced into the timber, is followed by a solution of chloride of lime, which decomposes the salt and renders

* This subject was fully treated in "European Railways" by Mr. Colburn and the author. Nothing essentially new in processes or results has been developed since that work appeared; and to it the reader is referred for a comparatively full statement of facts, and a description of the processes and apparatus.

the oxide of iron insoluble in the wood. This is Payne's process.

Pyrolignite of Iron. This is also Creosoting.

Size and Distribution of Sleepers.—The sleepers used on English railways are in general 9 feet long, 10 inches wide and 5 inches thick. These dimensions, with the usual distances at which the sleepers are laid, give a large bearing surface on the ballast, while the length especially tends to maintain the steadiness of the track, and prevents the rolling due to a firm bearing between the rails only. The usual distance at which the sleepers are laid is 3 feet from centre to centre. This gives 2½ square feet of bearing surface for each running foot of track. In another chapter, on rails, it will be shown that sufficient stiffness is provided to permit this wide span between sleepers without appreciable deflection. The lines of heavier traffic, as the London and North Western, have a distance of 2 feet 6 inches to 2 feet 9 inches between centres of sleepers, giving in the first case 3 square feet, and in the second, 2·73 square feet of bearing per running foot of track. With a comparatively wide distance between sleepers, the ballast can be, and is, indeed, more likely to be well packed than where they are close. But this requires unusually heavy sleepers and stiff rails which will not bend in detail. On the South Western line, the sleepers were originally laid 5 feet apart, and there are portions still remaining where the distance is 4 feet, giving 1⅞ square feet of bearing per running foot of track. Insufficient bearing, however, is at this time mentioned by English engineers, as the worst feature of the cross-sleeper and chair system—insufficient bearing both of the rail on the timber, and of the timber on the ballast, since the latter, however ample, is not entirely under the weight. *The timber* springs and does not sleep ; and it is

proposed to make thicker sleepers to prevent this springing. If the English system is faulty in this respect, what shall be said of America?

The dimensions and intervals of sleepers on some of the principal railways of New York, are as follows: average number of sleepers in 9 roads, per mile 2,242; length in feet (4 ft. 8½ inch gauge), 8·07; average width of bearing surface, 7·2 inches; bearing per foot of track, forward, 2·04 square inches.

English railway sleepers are quite often squared to get the full bearing of the full width, and it is this width which is given as 10 inches. On the South Eastern and on the Great Northern lines, triangular sleepers are used. These are sawed, two together, from a square stick, and have 14 inches bearing surface for the rail, the right angle resting in the ballast.

English engineers are careful to adopt *uniform sizes and uniform spaces* for sleepers. The primary object of sleepers is to give a bearing upon the road-bed—a consideration which appears to be sometimes very much overlooked. For on many lines in America, this bearing is scanty in extent and very irregular, being supplied indiscriminately by short and long, and wide and narrow sleepers at very variable distances apart; while also the sleepers are almost always spoken of as "ties," a term well enough by way of distinction, but implying that their principal office is to keep the track in gauge—which should in reality form but a very small part of the function of a sleeper. A comparatively slight rod of iron, at intervals of a few feet, is all-sufficient to bind the track together, but a large extent of bearing surface is necessary to keep the whole from being crushed into the road-bed. The tendency is to force all the sleepers down, and hence those which are smallest will yield first; and the track will thus be disturbed much more than if all

settled equally. The Boston and Lowell Railway is laid, for one track, on stone sleepers. These, although somewhat rigid, do not make a very bad track so long as they are properly kept up. But whenever it has been attempted to substitute occasional wooden sleepers in place of those taken out from breakage, the track has been made inconveniently uneven. The difference of support was such that it was found practically impossible to use alternate stone and wooden sleepers in the same track. Where sleepers of different depths are employed, without ample ballast, the deepest may rest on an elastic bed, while the shallower sticks are frozen solid upon the surface of the road-bed. A difference of two inches in thickness has been found to make an extremely uneven road in the winter. A similar irregularity is produced by using sleepers of different sizes in the same track, unless they are carefully spaced closer in proportion as they are smaller. It would indeed be better that the sleepers were all small, rather than that some should be small and some large—even where but the same total number were to be used in each case.

Large, well-formed sleepers are thus a part in the *series* of provisions by which good and economical tracks are secured. The earthwork being made firm by its own ample width and by good drainage, the ballast being deep, clean, and moderately binding, and the sleepers resting uniformly over a broad surface, we have a strong and permanent foundation, on which, if the rails are well fastened, the whole must inevitably lie smoothly and quietly. It is by permanent smoothness in a track that we avoid constant crushing and churning of the ballast, avoid crushing and rotting the sleepers, avoid breaking the chairs or other joint fastenings, avoid crushing and breaking rails, and that we also *avoid the* great increase of resistance and the larger

increased wear and tear of machinery always accompanying a bad track.

THE LONGITUDINAL SYSTEM.—Under this head it is proposed to consider briefly those systems which give a direct support to the rail immediately under it and the load, such as continuous longitudinal sleepers, in various forms, and wooden or cast-iron blocks or bearers; in contradistinction from the ordinary cross-sleeper system.

Defects of the Cross-sleeper system.—If cross-sleepers are, say 7½ to 8 feet in length, the common standard in America, the principal bearing is between the rails; if they are 9 feet long or more, the bearing without the rails, except the ballast be wide in proportion, and as solid at the edges as in the middle, is less firm than at other points. But this principal bearing within the rails is not under the load; the track therefore rocks—an evil which increases very rapidly when once started; so that it is customary on many lines to loosen the ballast between the sleepers, and to confine the principal bearing to that part of the sleeper immediately under and adjacent to the rail. This however decreases the total bearing of the sleeper upon the ballast, since the extreme ends (with a narrowly and thinly-ballasted American line), and the middle of the sleeper, are only nominal bearing surface. Consequently, double the number of sleepers must be provided, to furnish sufficient bearing, at double the cost; and when laid, there is so little space between them that they cannot be well packed. Therefore these cross sticks cannot, and it is well known that they do not *sleep* under the rails, upon a common American road-bed. Now if wide, firm, and ample ballast is provided, the English practice shows that sleepers 5 inches thick and 10 *inches wide, although* more firm, do not lie perfectly still

under the trains. Since four points of the bearing of the sleeper are more than two feet from the load, they are not merely bearers but they are levers, and if they are not inflexible girders, they spring, and gradually mash down the ballast and beat it into dust. It is therefore proposed to increase the depth of cross-sleepers in England. Each cross sleeper also deflects and settles on its own account, without receiving any support from those adjacent. The longitudinal stringer, however, independently of what stiffness the rail may give it, is continually transferring its load to its adjacent parts.

Another serious defect in the cross-sleeper system is the destruction of the sleeper by the movement of the rail. Nothing more than a mention of this fact is necessary to convince those who are familiar with an American line, of the desirableness of a remedy. The rail not only mashes and mechanically destroys the timber, but it facilitates the entrance of water, and hastens decay. This is caused partly by the want of sufficient bearing surface of the rail on the wood, but more especially by the want of sufficient firmness in the bearing of the sleeper on the ballast, and the want of strength in the fastenings. On badly ballasted roads, or where the surface-bearing on the ballast is too small, it is very common to see some of the sleepers loose, or hanging by the rail. Thus, whenever a train passes, the sleeper is forced down with a crushing blow. Sound timber is often *worn* out; it is, therefore, of little advantage to undertake the cost of preserving wood from rotting, until a better system of bearings is employed. On some of the Austrian roads, where timber is valuable, the sleepers are planed smoothly all over, both as a means of preventing decay and of improving *the bearing* surface. On several roads where the flat-footed

rail is used, the sleepers are grooved by machinery to receive the foot of the rail. This aids the spikes in keeping the road in gauge, although it weakens the sleeper and hastens its decay, by giving a lodgment for the water. Comparatively, then, the cross-sleeper system requires a larger amount of timber and a very much greater width of ballast, than the longitudinal system for a given permanence of way.

Wooden Blocks.—In France, on one railway, the experiment was tried of cutting most of the sleepers in two at their centres, leaving one whole at every 10 or 12 feet to bind the track together. The object was to destroy the spring of the sleeper, which, taking a bearing on its own centre, will deflect at the ends by the weight of a train, and thus churn the ballast in such manner as to lessen its own bearing and hasten the general disturbance of the track. The experiment is understood to have succeeded well, and W. Bridges Adams, of London, has recommended the general observance of the same practice. The forms of cast-iron sleepers, thus far introduced, are generally detached rectangular blocks, either lengthwise or across the track, and these have been found to bear better and to require less frequent packing than the transverse sleepers. The practice of sawing the sleepers in two would not answer excepting the separated ends were well packed in ballast, as there would be a tendency to strain them from their fastenings—but, if these were secure, there can be no doubt that the bearings would be better than with the present whole timber. On the Boston and Providence line, some of the joint sleepers were at one time turned half round, forming longitudinal bearings. The results are said to have been good.

The cast-iron sleepers used elsewhere, which will be further mentioned, are quite as advantageous as to *form*, as in du-

rability of material. They are found to pack better and to lie more quietly. They do not spring out of the ballast and hammer back into their beds, on the passage of a train, after the manner of long elastic beams with a partial bearing. In short, they are bearers and not levers, and they utilise all their surface by transferring the load directly to the road-bed. Wooden blocks dressed to similar forms and sizes, and say 4 inches thick, would give all these advantages of form, besides furnishing ample elasticity, and dispensing with an amount of ballast between the rails, which would be indispensable to an equally firm cross-sleeper road.

The rail-joint proposed by Mr. Zerah Colburn, is a longitudinal or block-joint sleeper, being in fact, a section of Dimpfel's longitudinal system. It is very evident, from the principles and experience already mentioned, that this joint-sleeper would give all the advantages of the block or cast-iron system as to form, besides making a much better joint than the chairs or wood splices commonly used. The rail has an ample bearing on so much of the timber that it could not rapidly crush into it, and it has more vertical stiffness than a dozen ordinary wood-splices. The longitudinals would of course have the same bearing on the ballast as that of a common joint sleeper, and this would be effective bearing, under the load and not at the end of a flexible lever.

Cast-iron Sleepers.—The high price of timber, and the desire to provide a permanent way without the many disadvantages of the transverse sleeper system, have led several permanent way engineers to design varieties of cast-iron sleepers, some of which have been tested for a long time, and are now in use on some of the English lines.

The use of cast-iron for this purpose is so much a matter of *cost*, that the subject can claim no such attention

in America as it is received in England. The advantages of cast-iron as to form are of special importance. There, an ordinary road requires £420 per mile of single track for timber sleepers—these being preserved to last twice as long as those used on American roads—probably twice and a half. The plans proposed, of cast-iron, weighing from 255,000 to 358,000 pounds per mile of single track, would cost £1000 a mile, would probably last as long as wood, and would be worth a considerable sum as old iron when ultimately renewed. In the United States, the sleepers would cost say $550 a mile, the cast-iron from $5,000 to $9,000, making the consideration of cast-iron quite out of the question without some extraordinary advantages were to be derived from its use. It will be interesting, however, to observe the more prominent plans of cast-iron roadway brought forward in England.

Samuel's cast-iron, timber-cushioned sleeper, the property of the Permanent Way Company. The casting is 42 inches long, 16 inches wide, weighs 132 pounds, and gives 4·66 square feet of bearing surface, each sleeper. So laid as to make the total bearing surface equal to 1½ square feet per foot of track forward, would require 100 tons (of 2,240 lbs.) mile. For 2 square feet bearing per foot of track, 133⅓ per tons of 2,240 lbs. This sleeper was applied, for an experimental length, on the Eastern Counties' line, some time about 1850, or say 10 years ago. It has been repeatedly reported as doing well, but it has now been taken up because it was too light, and no more has been laid down. On the South Eastern line, Samuel's sleeper, somewhat improved in design, has now lain above two years, and is perfectly satisfactory in all respects. The bearing is on the surface of the ballast, the base is more concentrated than with the sleeper-tie, and this plan has therefore proved to

be easy to pack, to maintain a good position, and to admit of fair drainage.

In 1850 and 1851, 200 miles of P. W. Barlow's cast-iron sleepers without the wood cushion, however, was laid down on different lines—100 miles on the South Eastern, with old rails. Nine miles of the sleepers required to be renewed in the first five years after laying down. The present pattern is made in two sizes, one 38 by 14 inches, weighing 137 pounds; the other 53 by 15 inches, weighing 182 pounds. The first would give 3·7 square feet of bearing per sleeper, the second 5·52 square feet. Laid to give 2 square feet of bearing per foot of track forward, would require of the first plan 174½ tons, of 2,240 pounds per mile of single track. Of the large sleepers, 155 tons, of 2,240 pounds, would give the same bearing. These sleepers would be spaced, where laid down so as to give but 1½ square feet of bearing per foot of track forward, requiring 131 tons of small sleepers, or 116¼ tons of the larger pattern. It will be seen that the bearing of the rail in the wood is very short, rendering the wood very liable to crush. The bearing surface on the ballast is further below the rail than in Samuel's plan, requiring more bearing per foot of track to give equal steadiness. This plan also introduces bolts and nuts, which must be, to some extent, an objection.

M. De Bergue's cast-iron sleeper is also in some use. This is more concentrated in its bearing than either of the others, being nearly equilateral, or 20 by 14 inches, weighing 46 to 56 pounds, and giving nearly two square feet of bearing each, requiring but 100 tons (of 2,240 pounds) per mile, to give a bearing of 1¾ square feet per foot of track forward. With 20-feet rails, and blocks spaced 30 inches, centre to centre, this plan

would require 22,124 pieces per mile, being 4,224 blocks alone. The sleeper is designed, as yet, only for the flat-footed rail. It was applied on the Great Northern line, in a siding, where the traffic was so heavy as to wear the rails out in 18 months. The sleepers were of but ¼ inch thick castings, were 18 by 14 inches, and spaced 2 feet apart in the centres. When the rails were renewed, one-fifth of all the sleepers were broken. The thickness has been successively increased to ½ inch, and is now down of that thickness on the London and South Western and the Lancashire and Yorkshire railways—for small lengths only, amounting altogether to a few miles. It requires to be packed with fine sand, but the engineer of the South Western railway states that it is easier packed, and preserves its bearing better than any other plan of permanent way in use on that line. The castings require some care in cooling them at the foundry, but so far, on the South Western line, scarcely one per cent. of the whole number laid down have broken.

Greaves' Cast-iron Spheroidal Sleeper. This is in use on a few English lines, and has been laid down to a considerable extent on foreign railways. It is difficult to get precise and reliable information sufficient to decide its character. It has been disapproved of by some engineers who have tried it, from not having sufficient stability, from being difficult to pack, and from being somewhat rigid.

It is not necessary to trace further the application of cast-iron for sleepers, but it does deserve remark that these plans are found to take a better bearing, and require less labour in packing than the cross-tie system. Upon this point there is no division of opinion or experience. Stone blocks had disadvantages in their rigidity, in their own weight, by which they sunk in the ballast, and in the depth of bedding which they required—altogether sufficient to

countervail their advantages of form, and to throw them out of use.

With the plans of cast-iron sleepers, it is found that 1½ square feet of bearing, per foot of track forward, answers as well as 2½ square feet of nominal bearing of cross sleepers. If in consideration of the high price of timber, and the advantages heretofore indicated, the English engineers should use blocks of preserved timber, the bulk of sleepers would be reduced from 5,500 cubic feet per mile to 3,300 cubic feet, a reduction of 40 per cent. If the mere disposition of a smaller quantity of wood into a better form can affor advantages in the permanence and good condition of track and in labour and expense of maintenance, all railway companies are interested in the fact.

Longitudinal System of the Great Western Railway.—The longitudinal system of the Great Western railway, has been variously modified from time to time. The stringers have been tried experimentally 10 × 10 inches, and in deep strong ballast they make a good road; but the standard of main-line timber has long been 15 × 7½ inches, with transoms, 7 × 5 inches, and 11 feet apart framed with strap-bolts. The longitudinals are always laid to *break joints*, and the rails do so too, not only with the timber by an overlap of at least 3 feet 6 inches, but also with each other. The longitudinals, when well bedded and settled in the ballast, do not roll; they have 2½ feet of bearing surface per foot forward, which is the same as incross-sleeper roads. The rail is about 10 inches above the bottom of timber.

The great and excellent principle of the longitudinal system is, that it is *packed continuously*, and gives a bearing immediately under the load. There are no cross sills or other pieces under the main timbers, the transoms or ties being on the same plane.

But as carried out on the Great Western line, the longitudinal system has several disadvantages in respect of its own maintenance, although it is admitted to be easy on the rolling stock. As the rail peculiar to this system (the bridge rail) has been made deficient in vertical stiffness, and as the timber cannot compensate for the want, it follows, as is proved in practice, that the line springs on the passage of a train. And, in springing, the rail must crush into the timber. A practically stiff rail might bear up on irregular and remote supports, and might, if sufficiently stiff, lie smoothly on rough ground without ballast, but such stiffness can only come from the rail and not from the timber. If the rail "gives," the timber must give too, and crush at the same time. The bridge rail used on the Great Western is estimated to have but five-sevenths of the stiffness of the same amount of iron rolled into the usual form. Hence, from this want of strength, and from the yielding nature of the wood when pressed upon by the flat foot of the rail, the timber has been considerably "mashed" in, so that near the Paddington station, at London, cross-pieces of hard board have been interposed between the rail and the sill, so as to make a continuous floor for the former. The Great Western longitudinal system, for this reason especially, is rather more expensive as to maintenance than the cross-sleeper system. It presents a difficulty also in the way of drainage, for which it does not lie in the right direction. Being deep in the ballast and deflecting more or less under heavy loads, it forms longitudinal channels in which the water is likely to collect and remain, unless the amplest precautions are taken against the evil. There is also the difficulty of removing the sills when they require to be replaced—especially the delay, which is sometimes very inconvenient.

For the stability of all plans of superstructure and for the efficiency of drainage, the height from the underside of the sleeper, or from the bearing on the ballast to the top of the rail is important. The difference in stability and ease of drainage appears in striking contrast to those referred to.

The Great Western railway is one of the most expensive in England, as regards actual cost of maintenance. This may be partly due to its wide gauge, its heavy equipment, and the preponderance of its passenger business over that of freight. The cost has been as follows for three years :

	1854.	1855.	1856.
Cost per mile of road	£284	£360	£260
,, ,, run, about	8*d*.	8*d*.	6*d*.

This is considerably in excess of the cost of the same item for other English roads, excepting that for the South Eastern, which has some 100 miles of light cast-iron sleepers, and which has proved, on the whole, quite as expensive.

The Sandwich System.—Mr. W. Bridges Adams put down, seven years ago, on the Eastern Counties line, a short distance of track wherein the rails were supported throughout their length by side timbers 7 inches wide, bolted through, the timbers forming a bed of 15 inches, resting on the ballast. The common 5-inch rail was used. There was no deficiency of vertical strength, and hence the plane of the rail was preserved, and the timber was not found to crush, there being no mortising or tenoning, and the timbers being on the sides of the rail, there was no difficulty in removing them when necessary for renewal. And, being comparatively shallow in the ballast and not deflecting sensibly, the difficulty of drainage was diminished. This

plan, called the sandwich system, and now more largely used, overcomes the disadvantages of the ordinary longitudinal system.

More recently, Mr. Adams has modified this plan so that it might better embody the peculiar advantages of the system; and he and others have adapted it to the various circumstances of railway working. It is, substantially, a deep but light rail, suspended by the head between continuous longitudinal sleepers on either side, the sleepers being bolted together through the rail, every 3 feet, and the two rails with their sleepers being tied together by iron rods or wooden ties, every 6 to 8 feet, to preserve the gauge. The side timbers may be a little shorter than the rail, allowing room for a separate fish-joint and preventing the necessity of separating the rail and the timbers when the rail is to be reversed. Or the side timbers may break joints with the rail and with each other, the fish-piece being enclosed by the same bolts that bind the timbers together. This is undoubtedly the better plan, as it saves extra bolts and preserves the continuity of the entire track. And long sections may be reversed at a time, which will prevent the necessity of disturbing many joints.

The side timbers constitute the sleeper and rest directly on the ballast. This system embodies several distinct and important principles, viz.:

The rail is supported immediately under the head, the load being taken off through the side timbers, whereby the central web of the rail is relieved from all lateral strain which would cause it to buckle, and (serving only as a stiffening keel) can be much deeper and thinner than the web of a common rail, which must sustain the entire action of the passing load. The rail weighs 70 pounds per yard, is 8 inches deep and ¼ inch only in thickness. This

thin, deep rail has double the vertical stiffness of one 3½ inches deep with a ½-inch stem. The rail is 5½ inches deep, with a ⅜-inch web, and weighs but 60 pounds per yard. Thus these deep rails will not "bend in detail" or successively as the wheel rolls along, and will not, therefore, crush the timber. That this bending in detail actually goes on with low rails, the experience with the ordinary longitudinal system as well as the universal experience with the cross-sleeper system, fully proves. The bending crushes the timber, where a practically stiff rail would *distribute the pressure over an extended surface.* It is only by suspending the rail by the head and clamping it closely at the sides that it is practicable to employ a rail so deep as to be absolutely stiff under all loads. The side timbers also increase the stiffness of the rail about one-half.

That the rail does not crush into the timber—even a common 5-inch rail with a slight bearing surface —is abundantly proved by the fact that the wood and the iron absolutely rust together, and must be pried apart in order to be separated. An experiment of this kind on the North London line; similar results have been published. The timber suffers no mechanical depreciation whatever, after seven years' service under a heavy and constant traffic on the Eastern Counties, North London, and other lines. One set of timbers has been known to wear out two sets of heavy double-headed rails, equal to four sets of single-headed rails, and it is now attached to its third set. Therefore the timber may be preserved from decay by any process which does not decidedly weaken it, with peculiar advantage. Cross sleepers on most American lines are mashed and mechanically destroyed long before they begin to decay.

The whole depth of this superstructure would be but 5

to 8 inches—the depth of the rail itself; whereas, parts of the Great Western track are 13½ inches deep from the top of the rail to the bottom of the sills. The stability of the superstructure is in proportion to the coincidence of the plane of support with the surface of the rail. The longitudinal system, as usually laid, rocks laterally, owing to its height above the support. Adams's plan is but little more than one-half as high.

The motion of the trains over a sandwich track is extremely easy and uniform. There is a feeling of smoothness but not of hardness and rigidity. The rail has a *uniform* and elastic bearing. There is, substantially, the same amount of metal at all points. Rigid joint sleepers by the side of flexible intermediates and anvil chairs and joint fastenings are out of the question. There can be no injurious rigidity. Since the stiffness of the structure ensures smoothness in the entire tread of the rail, the mere elasticity of the wood is sufficient to relieve all the jarring common to a less smooth but more rigid system.

The timbers being bolted on the sides, can be easily examined, and, when necessary, easily renewed; a great advantage over the ordinary longitudinal system.

While sufficiently deep in the ballast to be well supported in place, this system is not so deep as to give trouble in drainage. The ordinary longitudinal system, 13½ inches deep, lying in channels of that depth, is difficult to drain, and the cross sleeper, if it has ballast enough at its ends to afford any adequate support, forms quite as deep a channel as the sandwich sleeper, which may, indeed, lie almost on the top of the ballast.

The uniform depth and quality of ballast required between the rails, and the extreme width of ballast required for the *cross sleeper* system are unnecessary for this. The whole

of the bearing is immediately under the rail. In proportion as the superstructure is deep, so must the quantity of ballast be increased. This plan would require the same depth of ballast, beneath the sill, as any other system, but *above* the bottom, three to five inches could be used with Adams', where the ordinary cross sleeper road, as made in England, requires a foot.

This is obviously the cheapest system known. The leading fact about it is, that by paying for one rail, two are secured. *It gives two rails for the price of one* rail of the ordinary weight. When the top is worn out, the track is simply reversed, and a new head is ready for service, having been preserved in the ballast, and not worn and notched by resting in chairs, as is the case with double-headed rails employed as usual.

Less timber is required than in the cross sleeper system, because every part of what is employed, is utilised. The sleeper is a bearer under the load, and not at the end of a lever; and less ballast is required, as has been already shown.

A modification of the wrought iron 7-inch beams now made, could be applied with this system. These beams now weigh 60 pounds per yard, and even this iron, suitably disposed, would fulfil all the conditions of strength.

The same timber is employed for cross-ties to preserve the gauge. The side timbers average 7¼ by 7⅜ inches, and give 2⅜ square feet of bearing per foot of track forward, and take a little more timber than cross sleepers giving the same bearing. The side timbers are fastened with wooden tree-nails and keys. At the joints, a pair of dishing plates, preserves the stiffness at that point. At all other points in the length of the rail, the wooden balks clamp the sides of the rail.

Another of Mr. Adams's plans consists of an 8-inch rail ⅜ web, 75 pounds per yard, and supported by timber 6¼ by 7¼, dressed to shape. A cast plate, recessed in the timber, is used at each joint. Size of plate, 18 by 6 inches, by ¾ inch. Weight 22 pounds. The principal object accomplished by this plan is the elevation of the tread of the rail so far above the timber that room enough will be left for the flange of the wheels without grooving the timber.

Mr. Adams's estimate for this plan is: (the English plan having double-head, with chance to reverse; the American rail having single head.)

Bearing surface on ballast	13,200 square feet per mile, single.
„ „ of rail on wood	2200 „ „
Cubic feet timber, per mile	5867
Vertical stiffness of rail	64
Weight of iron	132 tons 9 cwts.

One mile of American cross-sleeper system. Ties 2½ feet centre to centre.

Bearing surface on ballast	13,362 square feet per mile, single.
„ „ of rail on wood	704 „ „
Cubic feet of timber, per mile	6336
Vertical stiffness of rail	18
Weight of iron	108 tons 3 cwts.

Another of Mr. Adams's modifications, with a 6-inch rail, ¼ inch web, 40 pounds per yard, supported in two balks, averaging 6 by 4¾ inches, has a pair of wrought-iron joint-plates at each joint, 1 foot long, and weighing 3 pounds each. This plan gives 10,560 feet of bearing on the ballast per mile of single track, or 2 feet per foot of track forward. The rails have 2,338 square feet of bearing surface on the sleepers per mile. The rails per mile, are 62 tons, 17 cwt., and the timber 4,400 cubic feet per mile.

One of Mr. Adams's plans for forming a stiff founda

tion with plank, consists of cross pieces of plank, 16 inches long and 2½ inches thick, are placed under the whole length of the rail. Every 6 or 9 feet, one of these planks is carried across to the other side, to tie the track together. Beneath the planks is a keel, formed by lengths of planks, 7 by 2½ inches. The rail is rebated into the upper planks, and the whole structure is held together by staple bolts: cast brackets are used at the joints of the rails. There are 4,470 cubic feet of timber, giving 14,080 square feet bearing on ballast, and 2,640 square feet of bearing of rails on timbers. The upper timber, when decayed, could be easily slipped out at the sides. The whole would afford much vertical stiffness, the bearing surface would be near the rail, and the structure would be elastic. There is another mode, in which T-iron ribs, 25 pounds per yard, take the place of the vertical planking. This makes equal to a 65-pound rail, with 3,150 cubic feet of timber per mile, with the bearings as above.

Either variety of the sandwich system may be considerably simplified, if a superior quality of iron is insisted upon, by making the rail as nearly right angular under its head as it ca be rolled, so as to prevent the necessity of dressing the timber to fit the shape, for instance.

The groove for the flange may be very cheaply made by fitting a circular cutter in an ordinary wood planing machine and passing the timber through in the ordinary manner.

It has been objected that this groove will fill with ice in winter, uponNorthern roads—because ice occasionally forms entirely across the road-bed between the rails, to a height which sometimes carries the wheels on their flanges and causes them to run off the line. Now, since the timbers would not necessarily touch each other within an inch or

more, at their ends, any rain or snow water would run out of the groove. It is possible, however, that the groove might fill with sleet which would gradually turn to ice, and thus lift the flanges. This can be only settled by experiment. The timbers may be trimmed should this prove a serious objection. The last-named plan—raising the tread of the rail high enough to clear the flange—requires a little more weight of metal, but it most effectually prevents trouble from ice, and it obviates the necessity of trimming or grooving the timbers at all.

The only other objection to the sandwich system which has been mentioned, is that it will not last well without ballast. We never heard of any system that would. It is indeed true that a springy, mud-and-water road-bed absolutely requires a superstructure that will yield and accommodate itself either to churning the earth in wet weather, or to following the undulations it may have assumed when caught by the frost. On such a foundation the superstructure must either be light enough to ring and twist without permanent set and strain, or else it must be provided with hogging frames like a North River steamer, in America, so that it may transfer its bearing a hundred feet each way, till it can find enough bottom to carry its load without deflection. And as road-beds approximate to this condition, they are likely to strain a stiff sandwich rail more than they would strain the common American deflecting chain track. Still, it is not probable that any such disadvantages, on an ordinarily good American line, would offset to any appreciable extent the decided and signal advantages of easy traction and the double life of the rail. A little ballast, however—half what would be required for a first-class cross-sleeper track—would add to those already named, the *crowning* benefit of cheap maintenance.

Here is another chance for the practice of tampering with standard improvements, and modifying and mutilating them till their valuable features are entirely lost; and we expect to hear the sandwich system condemned by some "shrewd railroad men," who will make an utter failure of some essentially different and absurd sandwich system of their own. To those who really wish to avail themselves of the long and successful practice in England in this matter, it is hardly necessary to repeat the fact that a *deep* rail, though not necessarily a heavy one, is absolutely necessary to the full success of this system. A shallow rail, supported under the head only, will deflect under each wheel and rapidly mash the timber, loosen its fastenings, and go to pieces. A deep rail is literally the backbone of the whole system. And it will, in all cases, be found highly economical to insure at least a foot of good clean ballast under the sleepers.

There is no mistake about the excellence of this system. It is peculiarly adapted to America, as it furnishes an excellent track without the excessive use of iron—without requiring any more iron than is now employed in a second-class cross sleeper road. And, in this country, it is patent to the public. Its advantages may be briefly reviewed as follows:

1st. Its first cost is less than that of a medium cross sleeper road, that is to say, a good American road.

2nd. Its cost for maintenance can hardly be half that of maintaining a good cross sleeper line.

3rd. Two rails are furnished at the price of one.

4th. The firm, non-deflective, and uniform tread of the rail, decreases the cost of traction in like proportion.

5th. The maintenance of rolling stock is decreased in the same degree, for similar reasons.

It *should be further* remarked, that the joint fastening

of a deep girder rail, like either of those contemplated or used in the sandwich system — that necessarily vexed question which can never be satisfactorily settled in case of shallow rails — is fully provided for. A fish-joint, deep enough to preserve the stiffness as well as the continuity of the rail, and situated between the nearly parallel tables of such a rail, so that it shall require but little pressure to keep it in place, certainly fulfils every attainable condition of a thorough joint as to lightness, cheapness, strength, durability, and elasticity. Thus circumstanced, the fish-joint requires but slight fastenings, since the strain is almost solely a vertical strain on the fish-pieces themselves, as girders resting on firm supports, and a tensile strain on the web of the rail. And when inclosed, two extra bolts, at most, are all that are required to hold it in place. Again, the only difficulty ever experienced with a deep fish-joint, is the loosening of the nuts; in this case, the elasticity of the timber is found to keep the nuts tight, by constantly straining the boltheads and nuts apart, and creating a degree of friction against which they cannot easily turn.

Dimpfel's Longitudinal System.—One form of this system is a double or single-headed rail, supported both under the head and under the bottom flange by continuous longitudinal sleepers. With a deep double-headed rail, the extra depth of timber is quite unnecessary for both stiffness and for bearing of the rail on the timber. Whatever may be the theoretical opinion of American practitioners who have not observed the working of Adams's sandwich system, the fact is, that the small bearing under the head, in case of a deep *rail,* is quite sufficient. The rail and timber would hardly rust together if there was play between them. Therefore, any *extra depth* of timber not only requires more material, but

embodies the serious defect before mentioned, of top-heaviness. And if top-heaviness is prevented by deeply embedding the sleeper, good drainage will be impossible.

But while Dimpfel's system is not likely to be a successful competitor of Adams's, it may still be a great improvement over the cross sleeper system with the common rail. The modification or adaptation of it, by Mr. Colborn, to joint sleepers, has already been mentioned. The deficient stiffness of a low rail is compensated for by an increase of bearing. A common American rail, then, which makes a moderately smooth and uniform track, on cross sleepers, would be certain to answer much better on at least four times the bearing. The only serious objection to the plan for the ordinary pattern of rail, is the height of the rail above the base of the sleeper; but this is not likely to offset the decided advantages mentioned. It is still an improvement upon the Great Western longitudinal system, and its modification on some of the Southern lines in the United States.

Seaton's Longitudinal System for street purposes has been long enough in use to prove its advantages over the cross sleeper system. It has some obvious features of simplicity over the sandwich system, but these are not necessarily advantages, because Seaton's system requires a heavier rail, and therefore a larger first cost than Adams's, although when laid as it should be, it is unrivalled in surface, gauge, and economy of maintenance by any permanent way that has come under observation. A 90-pound rail has been employed with this system on part of the London and North Western and the Great Western lines since 1857. The saving in first cost, over a first-class English cross sleeper system, with an equally heavy rail, is said to be about £100 per mile. The cost of maintenance is estimated from data which are believed to

be authentic, as one-third less than that of the best cross sleeper system. Upon examination in 1859, after the passage of about 100 trains daily, for two years, the rails showed no abrasion at the joints, while the fastenings of the rails to the joints and of the longitudinal timbers to the ties appeared absolutely tight, and did not appear to have been repaired or touched since the rails were first laid. The ballast was not superior to that on several of the best American roads. Upon removing one of the rails from the timbers, the creosote on the latter did not appear to have been worn at all; the rail had taken an even bearing on the whole of the timber which it covered, and had neither moved upon nor crushed into the wood. The screws were all tight and the joint fastenings firm. In addition to the general excellence of the longitudinal system, this modification of it owes its peculiar advantages to the following features:—The sleepers have the greatest possible bearing on the ballast, 17 inches width being standard; the whole structure is so low and has so broad a base that it has no tendency to rock; for this reason it need not be deeply imbedded in ballast, and thus interfere with drainage; not only vertical, but lateral support is given to the rail by the sleeper itself in virtue of their respective shape, and independently of the other fastenings, which are merely to keep the rail from jarring out of place. The great feature on which these systems depend for their excellence, is evidently so much stiffness in the rail itself, that it will not bend "in detail," or under each wheel, and thus mash into the timber. The unworn creosote on Seaton's timbers, and Adams's sleepers and iron *rusted together*, are absolute proof that no movement of the *rail occurs—that it* does not bend enough to mash into the *timber, but only* springs *with* the timber, just enough

prevent jarring. The rail transfers its load to so much surface of timber that there is no crushing pressure at any point. But if the rail is so light as to yield at any one point more than the elasticity of the timber will allow, the timber must be crushed, and the chief advantages of the system are sacrificed. While Adams's rail may be very light and still sufficiently stiff, on account of the thin deep web admissible, Seaton's entire rail must be proportionately heavy. It does not make the most economical use of iron, however simple may be its fastenings. And for reasons already mentioned, it requires a fair amount of ballast, and would hardly do so well on a mud bottom as flexible straps of iron floated on cross sleepers. These points have been especially referred to in view of the fact that several American managers, still bent on the suicidal policy of saving first cost, are proposing to lay a mere angle-iron after Seaton's method, affirming that so long as the sleeper has bearing enough, 50-lb. iron is sufficient.

It would reasonably appear, in consideration of the principles and results mentioned, that the longitudinal system of permanent way, probably in the form of Adams's sandwich plan, or, if sufficient first cost will be undertaken, of Seaton's plan, will eventually supersede the cross-sleeper system; and that it will not only decrease the cost of traction and repairs, but happily settle the now vexed question of rail joints and fastenings. It is to be hoped that discredit will not be thrown upon these plans by the failure of "improvements" and modifications designed to save first cost. We know of no cheaper system, *fit to be used*, than Adams's sandwich system. To construct cheaper permanent way than we now have, with the expectation of saving in the long run, is perfectly unreasonable.

CHAPTER III.

RAILS.

Iron and Manufacture.—Iron made during the past ten years has generally proved quite inferior to that made previously. In 1835, the rails for the Stockton and Darlington Railway were made to the following specification. Best No. 1 coal-blast mine iron was, first, run out in a finery fire; second, puddled, and the balls shingled under tilt hammers; third, rolled into bars; fourth, these bars were cut, piled, heated, and hammered into blooms; and, fifth, these were reheated and rolled into rails. For the Leeds and Selby Railway, the iron was made nearly as above, viz.: Best No. 1 cold-blast mine iron was puddled and shingled into a bloom, which was cut and rolled into a best bar. This was again cut up and rolled into a rail, without any intermixture of inferior iron. Such rails sold considerably above the prices of "best" bar-iron.

Most of the rails made during the past ten years have been made of hot-blast cinder iron, the tops and bottoms not always reheated, but rolled directly from puddle bars into rails; recently, however, both English and American engineers are turning their attention to a better quality of iron.*

* The following is extracted from a specification made by the Eastern Counties Railway Company, some two years since, for 4000 tons of new rails:—"Each rail is to be made from a pile 9 inches wide and 9 inches deep, consisting of one bar of iron 9 by 1¼ at the top and bottom. The intermediate bars not to exceed 1 inch in thickness, and to be alternately 6 inches and 3 inches wide, so as to break joint. The pile is to be rolled *at a welding heat* into a bloom 5 inches wide and 6 inches deep, which *being again raised* to a welding heat, is to be rolled into a rail. The bars, *9 inches by 1¼ inches*, which form the top and bottom of the pile, are to

The rails for the Royal Swedish, and for the Bombay and Baroda lines, are made much in the same manner. The tops and bottoms, of reheated iron, are each made from a pile of puddled bars—the central bars being merely of puddled iron. The pile for the Baroda rails is 7½ by 12½ inches. That for the Royal Swedish rail is 9 inches square. In both cases, the central bars of the pile are to go through, that is, to be of full length. The tops and bottoms are sometimes, however, specified to be 2 inches longer than the others.

The size of the piles is to be particularly noticed. The following table will show the relative reduction in rolling.

Rail.	Weight of Rail.	Size of Pile.	Area of Pile.	Area of Finished Rail Section.	Reduction of Pile in Rolling.
	Lbs.	Inches.	Sq Ins.	Sq. Ins.	
Baroda Rail . . .	66	7½ × 12½	93·75	6·9	13·6 to 1
Eastern Counties	65	9 × 9	81	6·8	11·9 to 1
Royal Swedish .	62	9 × 9	81	6·5	12·5 to 1
American Rail . .	69	6 × 6	36	7·2	5 to 1

Thus the improved English rails receive from double to nearly three times the working given for the standard

be manufactured from such a mixture of ores (being all mine iron), as shall produce the closest and hardest wrought-iron, and shall be drawn from the puddle ball under a hammer, which shall be equal to a five-ton tilt hammer, into a slab 9 inches wide by 2 inches thick, which slab shall be heated sufficiently for its reduction to the required thickness of 1¼ inch. The bars, of thickness not exceeding 1 inch, for forming the central part of the pile, are to be manufactured from such a mixture of ores (being all mine iron), as shall produce the closest and toughest wrought-iron, and shall be drawn from the puddle ball under a hammer, which shall be equal to a five-ton tilt hammer, into a slab or bloom of convenient form, the sectional area of which shall not be less than 20 square inches, which slab or bloom shall be reheated sufficiently for its reduction into bars of the required thickness, not exceeding 1 inch *The use of cinder or cinder pig will not be permitted under any c cumstances.* The rails are to be dipped while hot, in hot linseed *and are to be* perfectly protected from the weather until this is

make of rail now in use in America. The American rail is rolled direct from a pile 6 inches square—the improved English rail is rolled from the pile into a bloom of say 6 inches square, which is subsequently rolled into a rail.

Within the last year, the Eastern Counties Railway Company has ordered rails to be guaranteed to last *seven years*, and to be manufactured in accordance with the general principles just mentioned. The price of these rails was little over £11 10s. per ton; meanwhile rails were selling in England for a trifle less than £5 10s. per ton.

Only a mill with heavy rolls and ample power can work piles from 9 to 10 inches square, but with piles of that size the rails would have more working on them and the iron would be made more dense. The same result would be approximated, however, by working a smaller pile into merchant bar, which might be cut and piled to make the rail. In the latter case, however, there would be a risk that the iron would not have enough cinder to weld well.

The puddle-balls have been usually squeezed, in English rolling mills, by means of "alligator squeezers." These have comparatively little power, and hence do not shingle the iron thoroughly. The rotary squeezer not being in use in England (to any considerable extent) the tilt or steam-hammer is much resorted to, for shingling the puddled iron. The hammer is, undoubtedly, much better than the "alligator," but is not so efficient as the rotary squeezer.

Should any of the rails laminate, break, or otherwise fail, within a period of three years from completion of order, the company will, at their own expense, take such rails out of the line, and the contractor shall be bound to exchange them for an equal quantity of sound rails, to be delivered when required, free of all cost, at the company's wharf, *Blackwall, or* the Peterborough station."

The hammer requires considerable *time* to work the puddle-ball, during all of which the latter is cooling. The ball, when first taken from the puddling furnace, is below a fair welding heat, and thus the hammer does not have its due effect. The rotary squeezer does its work in a few seconds, and acts equally upon all parts of the ball, thus clearing it of much cinder. During observations made at a large American rolling mill, the puddled bars shingled by a hammer, showed a waste of 12 per cent. from the pig metal from which they were made. The bars, made from squeezed blooms, showed a waste of 14 per cent., showing that the squeezer had expelled 2 per cent. more cinder than the hammer. In re-heating this iron, for covers for rail-piles, the bars from hammered blooms showed a further waste of 7 per cent., while those from squeezed blooms wasted only 5 per cent. Charcoal blooms are too hard, however, for a squeezer, and must be shingled by a hammer.

It will be observed that the wearing out of rails consists largely in the peeling of the top stratum of iron from the rest of the mass. Upon examination it will be found that there appears not to have been a sound and thorough weld between the stata. Since we know that a bar of superior iron is generally used for the top of the pile from which such rails are made, while the rest of the pile was of an essentially different quality, we only observe a result which might have been predicted from the beginning—that metals which are not homogeneous cannot be rolled into a solid mass. There appears to be quite as much necessity for good iron in the interior as in the exterior strata of a rail-pile.

Much attention is being paid to the selection of the pig iron for conversion into rails. Cast iron varies in strength from 9000 to 45,000 pounds per square inch—a wide

range, indicating the necessity for a careful choice of material. Good pig, honestly and thoroughly worked, will make a good rail; and an additional expense of 90*s.* a ton in the manufacture of rails will give a quality that will wear *twice* as long, and hence be worth twice as much as the ordinary iron of the day.

WEIGHT OF RAILS.—The lighter the rail, the more thorough will be the working in it, for the reason shown in speaking of the sizes of rail-piles. The preference is now almost invariably in favour of lighter iron, as the heavy rails wear out soonest. It cannot be, however, because the rails are heavy, *per se*, that they go to pieces so fast—for the resistance of iron to wear and blows should be as its weight—for a similar quality in each case. It must be chiefly because lighter rails are better made, that they endure longer than heavy iron. The elasticity of a light rail, however, has something to do with its durability.

The 45-pound rails, made by the Ebbw Vale Company in 1837, for the Philadelphia and Reading railroad, have stood a wonderful wear. They were made similar to those already specified for the Stockton and Darlington line—their manufacture being superintended by Solomon W. Roberts, C.E., now of Philadelphia. The 64 and 68-pound rails, since laid down in their place, have gone to pieces with less than one-third of the same wear. The old rails—perhaps partly crystallised by their long use—and certainly worked dry of cinder in re-rolling, do not show their original superiority when reworked into heavy bars.

In 1854, rails of 85 to 100 pounds per yard were considered by English engineers to be the best. Since that time, it is found on the Eastern Counties line, that the *95-pound rails* made the worst road, were less durable, and

in course of time became the most dangerous—as compared with 75-pound rails. The London and North Western officers report that there are many more failures by breakage and in other ways, with the 82-pound rails than with the former 56-pound rails. None of the 62-pound rails, laid in the Grand Junction line, in 1837, were taken up until after 1849. The 80-pound rails then put down in place of the few removed, showed more wear after from twelve to eighteen months' use, than the old rails after twelve years' wear. The North London line, perhaps the heaviest worked in England, is having laid down 72-pound rails in place of those of 85 pounds, formerly used. The last rail—a ∩ pattern—for the Great Western line, is 62 pounds per yard, in place of 72 and 92-pound iron, formerly used. The South Eastern new rails are 65 pounds per yard—the old rails, 75. The Eastern Counties last pattern is of but 65 pounds, where one of 95 pounds was formerly used. The New York and Erie road has had rails of 58, 60, 63, 65, 68, 72, and 75 pounds laid down in place of 56-pound rails—the heavier iron almost invariably proving inferior.

The most favourite patterns of rails on continental roads are of 62 pounds per yard. In France, the heavy English patterns formerly used are being replaced by lighter iron.

Mr. Bidder has remarked, that the only way to get good rails was to contract for 85 pounds per yard, and to then arrange with the manufacturer to supply a better quality of 75 pounds per yard, for the same gross sum. The engineer of the London and South Western line, was offered, in 1857, new rails, delivered in London, at a price, while within twenty-four hours afterwards he was offered nearly as much for the old rails he had taken up after 19 years' wear. An American manufacturer, whose

experience has peculiarly fitted him to judge of the proportion of rails, when lately asked into *what form* he would dispose 70 pounds of iron per yard, replied, "I would use no such amount in any form."

The true course is in the use of the best iron, in moderately light rails. The cost *per ton* is increased but by a comparatively small amount, while the durability may be doubled. One advantage of a light rail is, that its very size insures more thorough working being expended upon it. So, in all the lighter rails ordered for English roads, the quality is provided to be greatly improved.

But recently, since American railway managers are getting into the fashion of using light rails, there is great danger of going to extremes. By decreasing the height and hence the vertical stiffness of rails to save weight, the bars bend in detail under each wheel, which greatly increases both the lamination and wear of the iron, and the resistance to the rolling of the wheels. To decrease the stiffness of the rail would be fatal to such systems as Adams' and Seaton's, for reasons already mentioned.

FORM OF RAILS.—The double-headed rail is adopted in England for convenience of fastening as well as for changing the wearing surface when one becomes worn. It entails the use of a chair on every sleeper, by which the cost of fastenings is much increased, and so, too, the bottom of the rail, bearing in cast chairs, becomes more or less indented, whereby it is often made unfit for reversing. Either table or head of the English rail contains but little more iron than is placed in the foot of an American rail, and this iron is not so favourably disposed for vertical strength in the thin, broad, as in the thick, narrow base.

The resistance of wrought-iron to extension and com-

pression, is as 90 of the first to 66 of the second. Hence, the head of a rail should be to its base (where it is not to be reversed) as 90 to 66. And the iron requires to be kept closely to the web, to afford its entire strength. At 3 inches from the web it would do very little good unless, as in Mr. Brunel's 6-inch wide base, to prevent crushing into the sleepers. With a rail of 2½ inch base, Mr. Barlow cut away ½ inch on each side, reducing the breadth to 1½ inch, when the strength was apparently *increased*. This, of course, was due to the slight inaccuracy of the hydraulic press used to make the experiment, but it showed that the strength could have been but inconsiderably diminished. The flanges are brought into use only by their lateral adhesion to the vertical web. Thus, while the base must be wide enough to prevent crushing into the sleepers, say 4 inches at least—this width is only for lateral stability—not for vertical strength.

But as the English rail obtains ample lateral support from the chairs, it can be and is made much deeper than American rails. A rail is merely an elastic beam, and the stiffness of rectangular beams is as the *cube* of the depth—doubling the depth increasing the stiffness eight times. The flanges on the rail somewhat modify this result.

If a rail deflects, the wheels must roll up a grade. Professor Barlow* found, in experimenting with the rails of the London and Birmingham railway, that the descent obtained by the deflection of a rail between any two fixed supports, gave no advantage of gravity, and that as much extra power was required as would be due to the ascent of a grade, equal to the slope of the deflecting surface, for one half of each bearing of rail, or,

* Barlow on the Strength of Materials, 8vo.

in other words, half of the deflecting slope for the whole length of line.

That rails do deflect is proved by the oozing out of mud from under the sleepers in wet weather, and the continual product of dust in the same place, in dry weather. The experiments made some years ago, on the Camden and Amboy railway, showed the deflection of an ordinary rail under the weight of a 20-ton engine, at passenger-train speed, to be equal to a 45-feet grade against the wheel. Professor Barlow found the deflection of a 50-pound rail, 3⅝ in. deep, 3 ft. bearing, under a load of 5 tons *at rest*, to be equal to a 25 feet grade (·084 in a span of 36 inches). This would be increased from 50 to 100 per cent. with the same load at rapid speed. The experiments of the Parliamentary Commission on the application of iron to railway structures, showed in one case, where the load traversed at 30 miles an hour, an increase of deflection of 150 per cent. over that observed with the load at rest.

These were with the rail firmly supported by the sleepers. But the deflection of rails is as the *cube* of the distance between supports, and hence, if one sleeper should fail to give support, the span of deflection would be doubled, and the deflection itself increased eight-fold. If two contiguous sleepers should yield so as to give no support, the deflection would be increased 27-fold.

With American shallow rails, in case of trains at rapid speed,* and the sleepers not always giving full support, a

* It is perfectly established that the deflection of beams, when the load is in motion, is greater than with the same load at rest. Professor Barlow found that 6500 pounds' weight on a single driving wheel of an engine deflected a 45-pound rail, 3 feet bearings, ·12 of an inch when at rest, and ·177 inch, equal to a grade of 52 feet per mile, at 20 miles an hour. The Parliamentary Commission, on the application of iron to railway structures, demonstrated the same fact. The effect of passing *rapidly over ice*, so often instanced in this connection, is not to the

heavy grade is continually opposed to the passage of American trains. This must absorb much power, for, as has been mentioned, there is no advantage derived from the descent of the deflecting slope, above the loss by the irregularities, so that the ascent of the opposing slope represents a total loss of power. All that part of the deflection caused by the failure of the support of the sleepers, is chargeable to a bad construction or bad maintenance of road-bed. The remainder is due to the rail itself. The excess of power required to work the traffic of American as compared with English roads, corroborates this view. The former roads oppose the most resistance.

Depth being so important an element of stiffness, the lighter I rails now being put down in England, are of the full *depth*—5 inches—of the former heavy rails. The reduction in weight is in the head and stem.

But if stiff rails are used, and they are not perfectly straight, or curved correctly in curves, and if the road-bed is not smoothly maintained, a fair amount of ballast being a condition of good maintenance, they will make a hard and rigid line, and will be rapidly split, besides doing much injury to the machinery. A light rail, once bent, will ease itself by its elasticity. A stiff rail, once out of line, will give and receive a blow. The Camden and Amboy line was laid partly with 7-inch rails, 92 pounds per yard. They proved too rigid, while from their great weight and the difficulty in rolling them, it is probable that they were inferior in quality. Rails of 4½ inches depth are being now put down on the same line with much success.

point. Ice does not represent an elastic beam with remote supports. It is supported uniformly by the water, and time is required to displace this.

It is to be remembered that all the iron which has stood such heavy traffic on English roads, for from 12 to 20 years, was from 4½ to 5½ inches deep—mostly 5 inches.

Depth is, among the considerations of form, very generally overlooked. On the other hand, there are certain popular opinions as to the form of rails which examination fails to support. One is that the steep "pear-head" is essential to strength, and another, that a very thin head and flange necessarily compel the use of the best iron.

The only possible use of a heavy pear-head is to prevent the edge of the rail from breaking down. Any more iron than is necessary to prevent such failure, is thrown away, as the iron is not in a place to assist the strength of the rail. The steep pear-head of the Buffalo, Corning, and New York road, and others, are rarely seen on an English road. If the iron in the head is sound, a very thin head is enough to prevent breaking down on the edge. This is proved as follows:

The head of the old Reading 45-pound rail, which stood an enormous traffic for 20 years, although very light, did not break down. It was made of the best iron. The edge of the head, after use, permanently deflected downward, the section being taken from the worn rail—the dotted line showing the original form. This shows that there was an advantageous elasticity in the iron of the head of the rail. In the Camden and Amboy old rail, after many years' use, the head, although very thin, did not break down as the iron was good. With the rail of the Boston and Lowell road, after having been run nearly two years on the bottom flange, it was found that the edge had taken a set of nearly ⅛ inch, without, however, breaking down. It has since run nearly four years more, the trial having commenced in the Autumn of 1854.

For very heavy English rails, the head is comparatively light—rarely averaging more than 1⅛ inch in depth, the inner corner, where the head unites with the stem, being a curve of short radius. As a general principle, the better the iron, the lighter may be the head of the rail, without danger of breaking off; and reciprocally, the lighter the head, the greater the probability that the iron will be well-worked, and consequently good.

It may be mentioned that many American roads are already availing themselves of this principle. The Boston and Worcester rail of the last pattern, is light under the head, similar to the old Harlem rail. The Michigan Central, new rail, is also very light under the head. The best rail ever laid on the New York and Harlem road, was put down 12 years ago, and has since sustained a very great wear; it was quite light under the head. That of the Cleveland, Columbus, and Cincinnati road was, together with Adams's bracket-joint, taken substantially from the design made by the author. This rail and joint, now in use on a fairly ballasted and drained road-bed, constitute one of the best sections of railway track in the United States.

But, on the other hand, a light flange does *compel* the use of good iron. Rails have been often laid out with very thin head and foot, with the express purpose of compelling the use of the best material. The designers did not know the character of iron, however. While *good* iron is likely to be improved by working it down to small dimensions, a very deep thin flange can be easier rolled from cold-short iron than from tough red-short. And such a flange offers a temptation to use brittle iron. The security from cinder, sought by means of a thin flange, is quite balanced by the exposure to the risk of cold-short iron. They must know

that the iron is originally good, and *then* put it in such shape as shall insure thorough working.

The width of head of English rails is generally 2½ inches —some are shown 2¾ inches, some 2¼ inches. Considering that the top is generally described with a radius of 5 to 5½ inches (or just the height of the rail itself), it does not make so much difference what the width of the head is, as the edge receives a bearing only when the sleepers are considerably worn. With newly turned tires, the bearing is theoretically but a point, although there is practically such deflection that the weight of the driving wheels of an engine, rolled upon a piece of gold-leaf, incorporated a portion of it as large as a sixpence, into the surface of the head of the rail.

Although rail iron crushes under a pressure of about 8 tons to the square inch, and although a wheel can bear theoretically, on but a *point* on the rail, yet the elasticity of the metals in contact may, without crushing, afford a bearing of measureable base. Suppose a 5-feet driving wheel to bear on a geometrical point merely on a plane rail—at a distance of half an inch on each side of this point, the wheel would be only ·0041 of an inch clear of the rail. This distance is about the same as the thickness of a sheet of the paper on which this book is printed. Were the tire and the rail to yield each one half of this — which both could probably do without crushing the fibre of the iron—a full bearing of one inch would be had: while an equal amount also would, probably, be obtained in the *width* across the rail, thus making a full square inch.

Almost inappreciable as this compression appears to be, it would, nevertheless, represent a grade before the wheel, equal to 43 feet per mile (·5 inch ÷ ·0041 = 122); or 1

in 122. If the actual contact was for $\frac{1}{2}$ inch on the rail, the resulting grade would be 22 feet to the mile. As the mere rolling friction of railway engines and carriages is nothing like what would be due to the gravity on either of these ascents, it is thus probable that the surface yields (to be restored by elasticity), under a very moderate pressure, and to a certain depth. The tendency to further yielding decreasing rapidly with great comparative extension of the bearing acquired, the compression is not such as to oppose a decided resistance to the rolling of the wheel. This compression is quite independent of the deflection of the rail as an elastic beam—the distinction can be understood by hanging a weight by a thin wire to a wooden beam; while the whole beam will be deflected, the fibres under the wire will be compressed or indented in addition.

Before concluding these remarks on form of rails, it should be observed that a high rail, moderately square under the head, is the best adapted for splicing at the joints. The ordinary American rail can never be well fished. It is so shallow that when the splices are punched for the bolts, the greater portion of their strength is gone. The under side of the head of the rail, also, is so steep that the splice cannot obtain a bearing sufficient to afford any considerable stiffness, except by a strain on the bolts beyond their strength.

Length of Rails.—English rails are usually 18 feet in length. Many have been made as short as 15 feet and 16 feet. Lately, the length is being made 21 feet. On the Manchester, Sheffield, and Lincolnshire railway, rails of 30 feet have been extensively used. The Rhymney Works once made a Barlow rail, 52 feet 6 inches long for the Paris Exhibition, but it is not probable that such masses of iron can be either economically or soundly rolled

Several long lengths of rolled iron have been made in the United States—iron was rolled at Troy for the Collins steamers of over 60 feet length, from piles of over 700 pounds. Wrought iron rafters have been rolled at Phœnixville, Pa., for the U.S. Capitol, 51 feet 2 inches long. Rails 30 feet long are now in large quantities rolled at several American mills. With the present appliances for making rails, piles of much over 500 pounds' weight are not likely to come out perfectly sound. Therefore, however desirable longer rails and fewer joints may be, these results seem to conflict to some extent, with the soundness of the bar.

RE-ROLLING RAILS.—Whether re-rolling old rails will result in a new product of good quality is entirely circumstantial. It can be told by working a sample of the iron, and in no other way. This subject is of very great importance to railway companies, and yet the most contradictory opinions exist in regard to it. Some say, without any qualification, that old rails should work up into the best quality of new iron—others, that they are all utterly worthless for re-working into rails. The officers of many roads go so far as to accuse iron-masters of retaining old stock, sent them for re-rolling, and putting off their customers with raw iron. Now, the *principles* upon which old iron is re-worked are perfectly simple, and if understood will often save much money as well as hard feeling.

The iron of commerce is never pure. It is an alloy of iron, carbon, silicon, sulphur, phosphorus, manganese, aluminium, &c. These foreign elements in proper proportion and mixture, form the cinder of the iron—without much cinder the iron is "burnt," and can never weld. In pig iron, these elements are in excess—the carbon so much so that the iron may be melted, as in ordinary foundry opera-

tions—whereas, when the iron is decarbonised by puddling, it only becomes *malleable* under a high heat—ordinary "wrought" iron. Not only is wrought iron chemically the same as cast iron, except in the *proportion* merely of the foreign matters, but wrought-iron, at every successive "working" or refining, while otherwise chemically unchanged, loses more and more of these foreign matters. Just in proportion as the cinder is worked out—or the purer the iron becomes—so will the iron be made softer and more fibrous, and at the same time become more difficult of welding. Iron with excess of cinder, although it is "raw," welds without trouble—provided there is neither copper nor zinc in it, nor an excess of sulphur. On the other hand, while a single old tire will *draw down* into the most excellent bolt iron, a *pile* of old tires, laid up in a heating furnace, would weld with some difficulty and irregularity, and if worked into a new engine-tire, would be quickly shattered to pieces.

Rails rarely *wear* out—they laminate or crush in the majority of cases. Where they laminate, it proves that they are not thoroughly *welded,* although crushing may occur from *too much* cinder, worked irregularly into the iron—and it often occurs from decay of cross-ties or bad ballasting.

Sound welding of the rail-pile being so necessary to form a good rail, it follows that only such iron as has sufficient cinder, uniformly distributed, can be depended on to weld well. In re-rolling old rails, it is thus entirely circumstantial whether the product will be a sound *bar*—although the iron itself will be improved in any case, and as a bolt, or a tension rod, would be stronger than before. The whole distinction is that between good *fibre* and good *weld,* and this distinction may be very wide indeed. Cast iron has the least fibre and the best weld.

The first thing to determine is, whether the old rail will weld readily. If the old rail was raw and cindery, it will be improved by re-working, and if worked enough, will infallibly make a good rail. But if, on the other hand, the old rail is of highly refined iron, such as the original Ebbw Vale, or "E. V." rails, it will not weld in re-working, and the product may go to pieces in three months under ordinary traffic.

This, although at first sight paradoxical, is really very simple. For while it amounts to the fact that an originally poor rail will, if not cold short, make a good rail by sufficient re-working, and that an originally very good rail will make an inferior rail by re-working—the reason is clear—the first was not worked enough to secure a good *fibre*—the second becomes worked too much to secure a good *weld*. Most of the very superior rails, laid down in America above twenty years ago, when re-worked into new rails, without liberal intermixture with new iron, have failed for the reason assigned. On the other hand, it might be expedient, in the case of very cindery old rails, to heat and hammer them into blooms, to be re-worked into bars for the rail-pile.

THE PHŒNIX IRON COMPANY'S PROCESS.—An important improvement in the manufacture of deep rails and girders with wide flanges. A tough red-short iron is likely to be unsound when squeezed from a solid square pile into the thin edges of a girder; for this reason the pile is made to assume the external shape and the proper arrangement of fibre of the finished product. The top and bottom parts of the pile are separately formed; the bars intended for the web are then keyed into place, so that the pile shall hold together under handling, and the whole of the iron

is then equally compressed between the rolls. Not only is the product made sounder, but its manufacture is cheapened by this process. And since the excessive squeezing required to change the general shape of a square pile is unnecessary, a heavier pile may be managed in the rolls, and longer as well as sounder rails may be produced.

THE TUBULAR RAIL.—The full-sized tubular rail of Mr. E. W. Stephens, as made at the Crescent Iron Works, Wheeling, and the various stages of its manufacture. It will be observed that, while substantially the ordinary pattern of ⊥ rail is preserved, it is lightened by the amount of iron left out of the head. By reference to the respective stages of the rolling process, it will be observed that the metal is more thoroughly compressed than the solid pear-head can be; more cinder is consequently worked out of it, and the metal is left comparatively dense, sound, and pure. The shrinkage of the hollow rail is observed to be 1½ inches less, after coming from the rolls, than that of the solid rail of the same weight, for 30-feet lengths, which indicates the purity of the metal, to some extent, although the temperature of the tubular bar is less than that of the solid bar, upon leaving the rolls. Experiments farther show that the tubular rail has more vertical stiffness and more elasticity than a solid rail of the same exterior dimensions. The greater density of the hollow bar would tend to promote its durability. This rail is now on trial; while opinions based upon some two years' use of it are generally favourable, it would be impossible to pronounce finally upon its merits.

THE CONTINUOUS RAIL.—Various patterns of the continuous or compound rail are seen in its history on the

New York Central Railway, where it has been thoroughly tested, and on other American lines, has been as follows: —The compound head of the rail, although presenting, for a few months, the best surface ever known on an American track, soon failed from the following causes: and when failure commenced, it was rapid and total. The wheels, worn concave on other rails with a narrower tread,* ran on the two sections of the compound rail alternately and did not always take a fair bearing on both; hence the wear was excessive. The lamination of the inside edges tended to sunder the two parts; and the action of frost was to strain or break the rivets and separate the sections of the rail. The next plan of continuous rail remedied the first difficulty mentioned, by providing a continuous base, but the abrasion of the head and foot at these points of contact, in the absence of a rigid connection between them, soon destroyed the rail. But the wear and tear of machinery, according to the testimony of the engineers of the New York Central, was considerably reduced by the superior smoothness of this rail. How much, is not definitely stated. It was therefore deemed advisable to make farther use of some form of continuous rail. Mr. Winslow, of the Albany Iron Works, then introduced what seemed to embody all the practicable features of the continuous system, and which has been quite extensively employed, with results, which, though obviously superior to those of the common American system, are not reported with accuracy. There are, however, certain principles bearing on the case, which establish the advantages of the continuous rail for certain purposes. These have already been referred to in speaking of elasticity of permanent way and of

* All wheels, in fact, will wear concave, without the tread of the rail is as wide as that of the wheel.

the longitudinal system. The continuous rail embodies some of the advantages of the latter system. A deep rail can obviously be fished in a more durable and economical manner than by making the whole rail in two parts; but such a rail requires a well ballasted road-bed, for if supported by an uneven or yielding bed, its points of ultimate support will be so far apart as to cause the rail to permanently bend; thus it will be both rigid and rough—the worst possible condition. A low and more yielding rail, however, will adapt itself to what bearing it can get; being flexible to a greater degree, it will follow the undulations of an uneven road-bed, and it will at the same time be slightly elastic, because it will bend in detail or under each wheel, and it will not be both *rigid* and rough, like a deep rail on a poor road-bed. Either a flexible rail or a tolerably good road-bed, appear to be necessary to any degree of econominal working. Of course there can be no comparison between the intrinsic value of these two plans—a deep rail on good ballast, and a flexible rail on sand or soil, or whatever road-bed is conveniently made. But if railway managers either cannot or will not perfect the beds of their roads (and we are sure that many of them would do so, if directors and shareholders did not insist on dividing all the money as fast as it is earned), the most reasonable thing they can do is to secure the best form of light flexible rail. But the first defect of the common low rail is quite as serious as that sought to be avoided by the use of a low rail, viz., the want of continuity and stiffness in the joints. For reasons already mentioned, continuous and uniform elasticity is especially important on an indifferent road-bed; therefore, anvil-chairs, or large masses of metal or even timber at the joint, are certain to cause more rapid deterioration at the ends of the rails than at any other points. It is simply

impossible to fish the joints of low pear-headed rails; any cheap method of preserving their stiffness, necessitates a large mass of metal and consequent rigidity. The most that can be done at small cost, is to preserve their continuity—to bring both ends down together. Therefore the common low rail cannot be economically jointed in any manner which will not compromise the result aimed at, viz., uniform elasticity.

The continuous rail is a compromise between these almost irreconcilable elements—continuous stiffness and continuous elasticity. It does not preserve the entire strength at the joints, but it prevents much deflection, and it preserves the continuity of the surface, that is to say, both contiguous ends of the parts of the rail yield together, so that severe hammering by the wheels is prevented. And the weight is the same at all parts, so that the elasticity is uniform. The price of the continuous rail is above that of a solid rail of equal weight. This makes the joints cost a trifle more; and the history of joints costing no more than this, has not, we believe, proved them to be superior to those furnished by the continuous rail.

Hard Rails.—The first requisite in a rail is soundness. If this is secured, the head may be made hard and the durability increased. But there is a risk, in attempting to unite hard and soft irons, that the weld will not be secure. Different irons bear different degrees of heat. The hard iron may be at a welding heat in the pile, while the soft or fibrous iron is yet below its own welding heat—or, while the latter is ready to weld, the former may be burning. In either case, the union of the iron is imperfect. Hard headed rails have been found to split or peel off, on English railways—Barlow's saddle-back rail was especially troublesome in this way. Uniformity of iron is important to secure soundness.

The Ebbw Vale Works has turned out specimens of rails made from steel produced by the Uchatius process. The quality of the steel is pronounced to be equal to that used for razors.

The heads of rails are being artificially converted into steel by Dodd's process of case-hardening. This is being practised on rails for crossings and about stations. Switches are being very generally steeled in the same manner. The cost of converting rails by this process is about £2 per ton.

It is not the practice in England to roll the steel into the rail-pile, as has been done, to some extent, in the United States, without much success, since the hard material peels from the soft, for reasons already stated. It is probable, however, that puddled or semi-steel, possessing so much of the nature of iron, together with its steel qualities, can be rolled so firmly upon iron that it will not peel. By this process, the cost of steel-headed rails may not be greater than that of iron rails, since less material will have equal strength and stiffness.

Conclusion.—The present movement as to rails turns chiefly on a better proportion of bar and a better quality of iron. It has been customary to waste twelve tons of iron per mile, worth £140, under the heads of our rails, for no other reason than that such inferior iron was used as to crumble down on the edge.

All the iron put in rails should be worked to double the amount generally practised, and while the whole cost might be increased one-third, the wear of the iron would be fully doubled. Experience has proved this again and again. English roads are taking up this reform in earnest, and some are paying above twice as much for their iron as the current prices of ordinary bars.

CHAPTER IV.

RAIL JOINTS.

This subject has already been referred to, in some detail, in discussing the different systems of permanent way.*

It is proposed to classify the various plans of joints and fastenings, and to refer to the principles and general results of each class. Since it has already appeared that the fish-joint—a simple splice between the upper and lower tables of the rail—is at once the most effective and economical method of jointing deep rails, and that deep rails are a necessary feature of the best permanent way; and since most of the other varieties of rail joints, besides the fish-joint, have not been long enough in service to warrant definite conclusions as to their respective merits, it is not proposed to go into a detailed discussion of their principles. All attempts to make satisfactory and thorough work in jointing our low, pear-headed rails, must result in eking out an intrinsically bad system of permanent way.

Classification of Joint Fixtures.—All fixtures at the adjacent ends of rails may be classified as simple chairs, splice of fish-chairs, and simple splices. The chairs merely give increased bearing on the sleepers (but rarely enough to prevent the mashing of the latter), and hold the rail laterally, but they neither transfer the stiffness of one rail to the next, nor preserve the continuity of the surface.

* See Report on the "Elasticity of Permanent Way," or Dempsey's "Railway Engineer," 4to, 1855.

They simply transfer the bearing of a projecting and deflecting rail-end to a single sleeper, which itself has not bearing enough on the ballast to support the load. The splice-chairs give the rails a seat, preserve their continuity, and may, but do not necessarily, preserve their vertical stiffness. They also hold them laterally. Splices simply preserve the continuity of rails, and may or may not preserve their stiffness.

1. The simple chair makes a very poor road, and is very extensively used because it is cheap. No chair at all would be cheaper and not much worse. This pattern of chair is sometimes made so heavy as to bring down both adjacent rail ends at the same time, or to preserve the continuity of the surface, when it fulfils the condition of a splice to a certain extent.

2. Splice-chairs are of three kinds: 1st, Sleeve or long lipped chairs—solid pieces not capable of taking up the lost motion caused by wear, and not stiff without deep vertical webs or ribs. When long or resting upon two sleepers, they have proved a better fixture for low pear-headed rails than most of the adjustable chairs, since they require no attention, remain tighter than ill-fitted bolts and keys, give so large a bearing as to prevent much deflection, and in any case allow only a slight vertical play between the rail ends. One device adds the advantage of the sleeve chair to those of the splice; it preserves the continuity and may preserve the entire strength of the rail, without causing excessive rigidity; the brackets forming the splice are welded to the bottom piece. Three sizes of this joint are furnished; of the largest size, the side and bottom pieces are respectively 18 and 15 inches long; of the second size, 16 and 13 inches long, and of the third, 14 and 11 inches long.

2nd. Bolted chairs, of which there are many varieties; some of those patented here were long before patented in Europe. Their leading trouble is shaking loose. Without expensive fitting, nuts will jar off. They therefore embody many devices for securing the nuts, but the longer English experience has proved larger and better bolts and nuts cheapest in the end. They are of several classes, those which gripe the foot of the rail only, and preserve its continuity but not its level, since the iron used is mostly in the neutral axis as to strength. Some have deep bottom-ribs and are very strong, but they bring the strain primarily on the bolts and nuts. Another class is a modification of the fish-piece, between the tables of the rail; it does not bring all the strain on the bolts, since these only hold it laterally in place, the web of the rail taking the strain of supporting the wheels. Both the fish and chair are sometimes in one piece, bolted laterally to the rail. The best modification has proved to be the Adams's bracket, which gives a fish and a bearing at one or both sides of the rail, on the sleeper. A single bracket-joint applied with a Z shaped rail, has some obvious advantages. The bracket gives ample steadiness and lateral support to a deep, double-headed rail. The peculiarity of the spike head and the nut fastening will be observed. In several cases, the sleeve-chair and the fish-joint are used together. The Camden Amboy ring-joint, on a chair, and some of its modifications, also raised sides of a chair to form a fish, and to carry the wheel over the break, are in exceptional use. The wooden splice alone is valuable for lateral support of the joint, and better than nothing for vertical stiffness. One great advantage of wood, in connection with bottom or side plates or both, is, that nuts resting against it will not easily loosen, by reason of its elasticity.

The best wooden joint in use, which is comparatively smooth, elastic, and durable, is ordinarily made thus: the bottom timber is 2 by 8 inches, and 2½ feet long; the side timber 3¾ by 4 inches, and 2½ feet long. The iron chair weighs 6 lbs., the bolt and nut, 1¾ lbs.; 2 bridge spikes, 9 inches long, take the place of 6 spikes. The whole costs about 2*s.* 8*d.* per joint. Another joint in use consists of a 33-inch bottom-piece, resting on two sleepers, a 36-inch side-stick, and a 17-inch iron fish-piece secured by two bolts.

3rd. Keyed joint-chairs are of nearly the same varieties as bolted chairs. Their grand defect is, that iron enough to prevent their splitting, as the key is driven, will give them an anvil-like rigidity. Wedges or keys under the rail, between it and the chair, if of wrought-iron, may be light, and are very effective as to continuity, though they give very little stiffness. Wedge fishes, or fishes fastened by keys, or held in place by longitudinal bolts, all tend to pry open the chair, and involve very great weight and rigidity.

The stiffness of all joints which gripe the foot of the rail only, has been found to depend on their length and their individual stiffness. Sufficient cost will make a good job, but no cheap, light structure will answer, although a device which will bring both adjacent ends of the rail down, when one is depressed, is found to prevent much lamination. The value of the fish principle depends mainly on the shape of the rail. If this is high, the high splice of fish it allows will be stiff, and if square under the corners, the splice will bring little strain on the bolts or keys, and will hold fast in its place. Mr. Adams has proposed to employ pieces of old, laminated rail, for bottom splices. His method of fastening them is obviously impracticable. The use has been suggested of long gibs or troughs of

rolled iron to hold the two rail flanges together, these gibs to be prevented from sliding off the flanges of the rails by pins put through them and the flanges. The plan is on trial.

A form of splice-chair, neither keyed nor bolted, has been but lately put down. The Adams bracket hooks at the bottom of the rail, upon a sleeve-chair or bottom piece, so that when the joint tends to settle, the least downward motion hugs the fish part into its place, and draws the opposite lip of the bottom-piece close upon the foot of the rail. There are no nuts nor keys to jar loose, and the weight of the train tightens the joint.

Simple fish-splices are used upon and between sleepers. The suspended joint is too elastic with a low rail and bad ballast, while the joint on a sleeper, without a uniformly smooth road-bed, is too rigid. The general principles of the bolted splice chair, as mentioned, apply also to the simple splice. A wedge-splice, held laterally in place by projections, formed upon the bottom of the head and the top of the foot of the rail has proved valuable as far as used.

The excellence of the fish-joint in all cases where rails are deep and nearly square under the head is obvious. The tensile strength of the web of rail itself resists the downward pressure of the wheels, that pressure being transferred through simple plates of iron standing on edge. All that is required of the fastenings of the splice is to hold it laterally in place, and if the rail is nearly square under the head, only slight fastenings are required—in fact, the splice would remain in place without fastening, while the weight was upon it. If the splice is at any other point than between the upper and lower tables of the rail, its *fastenings* have to resist the weight of the train.

It was originally intended, when the fish-joint was pro-

posed in England, to employ two sleepers six inches apart at the joints, and to drive a plate, a little wedging, between the jaws of the two chairs and the side of the rail, covering the joint equally on each side. This was never adopted, but instead, the sleepers were removed, say 12 inches, each way from the joint, and a pair of plates, say 18 inches long, three by $\frac{3}{4}$ inches, bolted together through the rail by four $\frac{3}{4}$ or $\frac{7}{8}$-inch bolts, an allowance being made by oval bolt-holes for the expansion and contraction. The fish-joint, upon this general arrangement, was designed by W. Bridges Adams in 1847, and has been applied throughout the London and North Western, the Eastern Counties, and some other lines. It is being extended to the London and South Western and others. The French are beginning to adopt it. The Indian and the royal Swedish railways have it down or contracted for. The fish-joint with key-bolts, was first used by Robert H. Barr, of Newcastle, Del., in 1843, but with the low American rail, it had soon to be discontinued.

It has been stated, that the underside of the head and upper surface of the foot of the rails, require to be of a shape to afford a good bearing for the plates. In this respect, English rails are always superior to the common American pattern.

The want of perfect fit, and of further provisions for taking up the wear on the edges of the plates, has caused them, in some cases, to get loose. The nuts often tend to work loose—on some lines apparently to a great extent. The outward strain is such that, as soon as the nuts are loose, all support is gone. Much of whatever difficulty is experienced, undoubtedly arises from inferior workmanship. The fish-plates, bolts, &c., are contracted for in large quantities at low prices, and the mechanical arrangement

is not responsible for consequences due to such causes. In punching fish-plates, unless care is used, they are apt to be swelled on the edges, opposite the holes. This may reduce, as it often does, the actual bearing to one-eighth its intended amount. The nuts are quite apt to be convex faced, by which their holding friction is greatly reduced. The bolts are apt to be cut with a rough thread, by which their hold is greatly lessened. So, if the holes are not accurately punched in coincidence with those in the rails, the strain, especially when the rails alter their length by heat, would naturally work the joint loose. Thus the quality of the workmanship exercises so important an influence upon the stability of the arrangement, that thoroughly good work must be understood, from the start, as quite essential to any success.

Yet there is an undeniable tendency of the nuts to work loose—there are probably twenty devices, patented and unpatented, for retaining the nuts of fish-joints in place. Mr. Adams proposes to chamfer the inner edges of the nuts, and to drive a flat dovetail key between them. This reduces the bearing surface of the nuts. The fish-plates of the Royal Swedish railways have concave faced nuts, by which the corners get a hold in the side of the plate. The fish is a very thorough job. A split key outside the nut, cannot fail to keep the latter tight.

The fish-plates must not, of course, come in contact with the sides of the middle web of the rail, as room is required to draw them to fit when worn, and as there is an elasticity, when they bear only on the edges, which relieves the jar on the nuts. The nuts of some of the fish-joints used in France, are made with a conical end, screwed into a countersink in the fish-plate. Some of the English fish-plates are now grooved on their sides, to hold the head of the

bolt, and to catch the nut when it turns square with the groove. This weakens the fish. The fish-plates of several of the French railways are similarly grooved for the bolt head only, which is made of T form. These plans appear to regard it as necessary to prevent the bolt, rather than the nut, from turning, but of the two it would appear that the nut was much more in need of this protection. A plan of bolting the fish-plates through the joints of two chairs is one of the "fighting patents," so called, of a company interested in railway inventions, and is not, as we understand, adopted in practice.

Samuel's double-fish show Pole's tapped joint, where all the bolts are screwed into one of the fish-plates. This avoids the nut, which is apt to be in the way of the flange of the wheel, and, doubtless, secures a good hold of the bolts. But it requires an accuracy of work hardly to be expected in such materials. If the holes are not tapped in one plate exactly in coincidence with those punched in the other, the bolts would be greatly strained, there being a tendency to wring them off in the neck in turning them up, and to prevent also the head from taking a good bearing. If a bolt should thus break off in the fish-plate, it would prove very inconvenient to remove it. Right and left screws for this purpose, are open to the same objections, and to a greater extent. The joint may have any amount of stiffness by deepening the fish-plates. The method of fastening it is very simple. This joint has been severely tested, and has been in successful use for a year on the New York Central road.

The fish-plates on English lines are usually 18 inches long. For the Royal Swedish railway, they are 15 inches. For the North London line, they are 27 inches long. They

are sometimes rolled as a trough, but are more commonly made flat and chamfered on the outer or inner edges—where the stem of the rail is vertical, generally on the outer edges. The bolts are commonly $\frac{3}{4}$ inch—more lately they are made $\frac{7}{8}$ inch in diameter.

Defective workmanship and badly-shaped rails have in some cases rendered the fish-joint abortive. This has been the case especially with the suspended joint. On the Eastern Counties line, after being used between sleepers, for several years, it is being gradually removed. The fish-plates, after use, show an abrasion of their upper and lower edges, in such way that they *appear* to have been bent. But between the points indicated as the original positions of the ends of the rails, a burr is left on the upper edges and on the inner sides—from which may be seen how the iron has been worn away from these points. That good fish-joints are largely a question of workmanship may be readily observed by comparing those on the South Eastern and on the Brighton lines, where they run side by side; on the former the joints are well made, and they are rarely loose. On the Midland Railway, the deflection of the fish-joint was found so troublesome that a sleeper was driven beneath the joint. This sleeper was merely left loose, and could not, therefore, have its proper effect. The deflection of the fish-joint may be readily observed during the slow passage of trains. Its stiffness may be easily increased. On the Northern Railway of France, some 350 miles of 5-inch flat-footed rail, is laid with fish-joints resting on sleepers without chairs. The two adjacent sleepers are 30 inches from the joint sleeper; the rest are 36 inches apart. This appears to be all that is required for the 34-ton Engerth engines. On the Eastern Counties line all the bolts and nuts of the fish-joints were renewed in 1856, and the cost of this was

equal to that of all other repairs of the line. It is the intention to remove this joint altogether from this line; on which it is now laid down for 1,000 miles of single track. The rails, however, to which this joint had been originally applied, were old and of a form unfavourable for obtaining a proper bearing of the fish-plates.

On the Great Northern line, an examination of 250 consecutive joints, showed that 261 bolts (26 per cent. of the whole) were loose, and six came entirely out within 48 hours after they had been carefully tightened up. The nut, when firmly screwed up, takes a certain bearing in the thread, and by the strain upon it must insensibly produce a change in the form of the thread—so much, that being afterwards screwed up to a new position, it will tend to work back to its old bearing—and with this, the structure is again loose. This tendency can only be restrained by making:—

First, fish-plates of good strength, with a bearing of but moderate angle with the horizontal line of the bolt—say 30°. *Second,* making the bearing of the edge of the fish-plate continuous, instead of at the swellings caused in punching the holes. *Third,* making the bearing a surface instead of a line—fitting to at least half an inch of the width of the under side of the head of the rail. *Fourth,* making good fitting bolts, straight and square under the head. *Fifth,* employing all the available friction surface of the nut. *Sixth,* making a full, clean thread in the nut.

To this must be added a certain lateral elasticity in the plates themselves, by making them deep and thin (where the rail is deep enough), and in all cases fitting the plates so as to clear the sides of the stem of the rail.

In short it may be laid down as a rule that with a good form of rail, and with careful workmanship, the fish makes a good job with the ordinary cross-sleeper system. Its peculiar excellence for the sandwich system has been already referred to.

Almost if not all English railways are laid with joints opposite; that is to say, on the same sleeper. In the United States, as is well known, opinion is divided upon this practice. It has been usual to make both joints on the same sleeper. The arguments against alternate or broken joints are those which apply in the case of a very bad track. One of them is that the alternate yielding of the joints causes the train to roll, and that the blow taken at each joint tends to wear out the middle of the opposite length of rail. These arguments assume the very state of things, however, which it is the purpose of broken joints to avoid. For the yielding and blows at the joints must be much less where each has the full bearing of an entire sleeper to support it. Thus, while there are twice as many shocks with alternate joints, they are each reduced to less than one half the force of the shocks with opposite joints—twice as many sleepers and a portion of the strength of the rails being interposed to lessen their effects. The great objection to the rolling motion given to the train, is that its effect upon the running gear is more destructive than the simple vertical motion caused by opposite joints. With properly fastened joints, however, the rail will be practically continuous, and it will then make no difference where the joints are placed.

The allowance for the expansion of joints is, of course, the same in all countries, with equal variations of climate. The necessary allowances for a 20-feet rail are as follow:

At 100°	place the rail in contact.		
90°	at a distance of	·016	inch.
80°	„ „	·032	„
70°	„ „	·049	„
60°	„ „	·065	„
50°	„ „	·082	„
40°	„ „	·098	„
30°	„ „	·114	„
20°	„ „	·131	„
10°	„ „	·147	„
0°	„ „	·163	„
−10°	„ „	·179	„
−20°	„ „	·296	„
−30°	„ „	·212	„

A variation of 10° or 12° is said to produce a force of expansion in iron, equal to one ton to the square inch. A variation of temperature of 150° would thus, in its produced expansion or contraction, cause a strain equal to the strength of the iron itself. Engine tires, however, are often stretched *one inch* in a length (of circumference) of sixteen feet; and although the interval from a red heat to being cooled with water is not two minutes, the iron is not weakened. Iron is indeed strengthened by being subjected to tension while at a high temperature. Professor Johnson found a gain of some 20 per cent. to be due to what was called "Thermo-extension."

Track, in the United States, where laid with close joints in cold weather, has been raised vertically one foot, and thrown laterally two or three feet by expansion. In England, the same thing has occasionally happened. In June, 1856, a train running at 40 miles an hour was thrown off the *inside* of a curve, on the North Eastern railway, in consequence of the rails being bent by restricted expansion. This was with 82-pound rails, fastened every three feet by heavy chairs, and fished at the joints.

On the other hand, several interesting examples show that the fastenings may be sufficiently strong, or that the heat absorbed by the rail may be so carried off by the